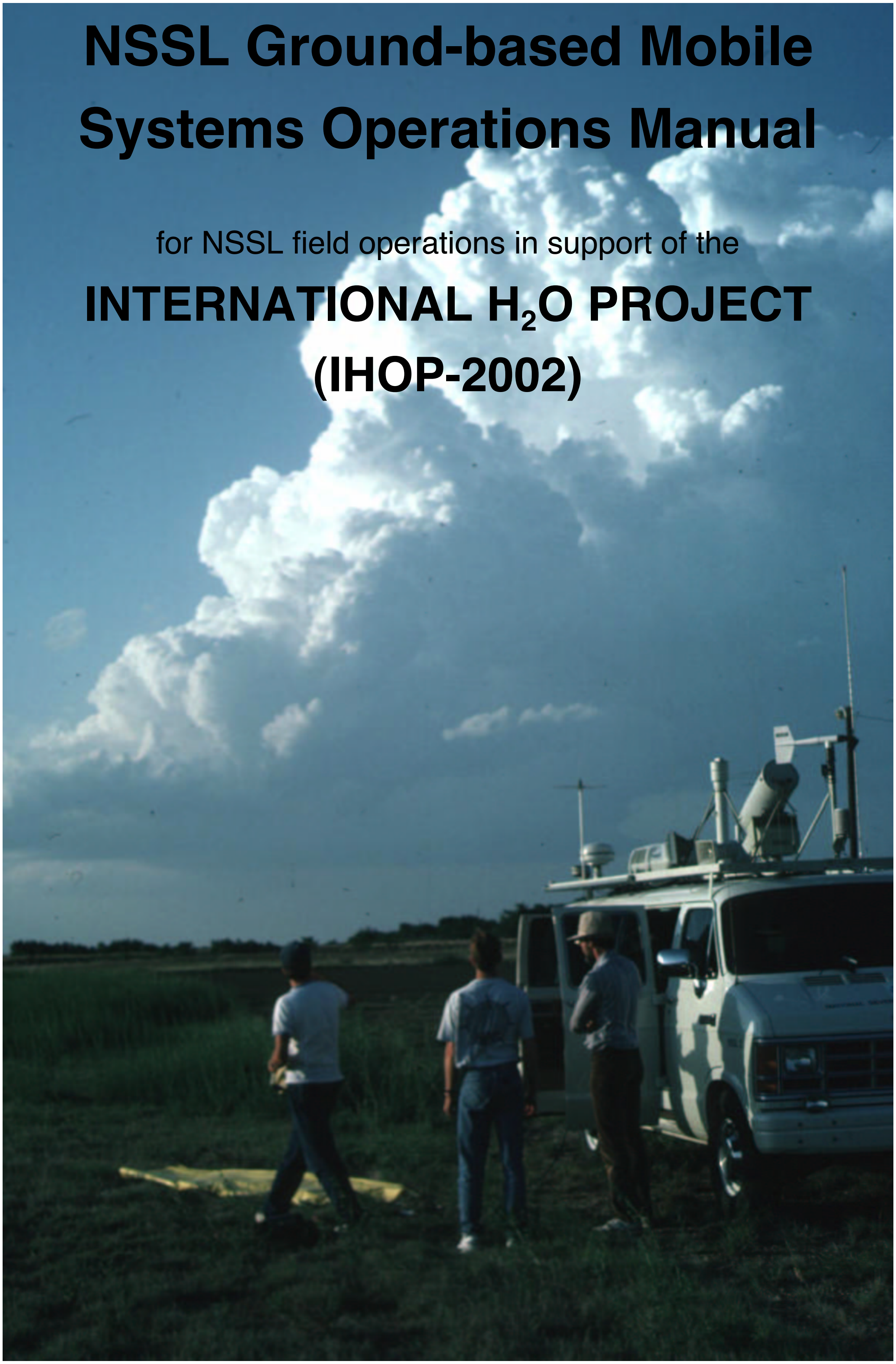
NSSL Ground-based Mobile Systems Operations Manual

for NSSL field operations in support of the

INTERNATIONAL H_2O PROJECT (IHOP-2002)



NSSL Ground-based Mobile Systems Operations Manual

for NSSL field operations in support of the

INTERNATIONAL H_2O PROJECT (IHOP-2002)

National Severe Storms Laboratory
10 May 2002
(revised 11 May 2002)

Conrad Ziegler (NSSL)
Erik Rasmussen (CIMMS/NSSL)

Acknowledgement: The NSSL principle investigators in IHOP are grateful for the support of the National Science Foundation (Dr. Stephan Nelson), the NOAA High Performance Computing and Communications program (HPCC), the NOAA/United States Weather Research Program (Dr. John Gaynor), the Director of the National Severe Storms Laboratory (Dr. James Kimpel), the Director of the Center for Analysis and Prediction of Storms (Dr. Kelvin Droegemeier), the Director of the NWS/NCEP/Storm Prediction Center (Dr. Joseph Schaefer), and the ATD Division of the National Center for Atmospheric Research.

(Cover page: Photo during COPS-91 experiment, looking N at 0040 UTC on 16 May 1991, with NSSL-2 M-CLASS in foreground and developing Wheeler County, TX dryline storm in background. Photo courtesy of Dr. Carl Hane, NSSL)

CONTENTS

1. OBJECTIVES AND CHALLENGES 1

2. CONVECTION INITIATION HYPOTHESES 4

3. FIELD STRATEGY 9

4. TEAM DESCRIPTIONS: MISSIONS AND PERSONNEL 17

5. COMMUNICATIONS 29

6. SAFETY AND PERSONAL CONSIDERATIONS 34

CHAPTER 1. Objectives and Challenges

The International H_2O Project (IHOP) has committed to target boundaries with an array of mobile, ground-based observing systems, termed the "armada". The objectives are to document the morphology and evolution of boundaries, the ambient mesoscale boundary layer (BL) structure, and the convection initiation (CI) process. Long time-duration sampling is required for overlapping and redundant measurements and to achieve specific science goals (e.g. document flow of moisture to bases of initiating convection by calculating air trajectories in detailed context of other measurements). It is imperative to maintain continuity of sampling at the original target location if a boundary persists. A simple yet adaptive field strategy is required for monitoring the evolving BL. For example, if the original target boundary dissipates, and a new boundary begins to form nearby (ie. discrete propagation), the armada must be ready to redeploy. Any redeployment must be rapid, as some key ground-based sensors do not collect data while moving, and since the BL at the new location might be evolving toward a state capable of supporting CI.

Targeting at cloud-scales will require effective integration of field observations in near real-time by a mobile Field Coordinator (FC). It will be challenging to acquire and track target boundaries in real-time at the small spatial and temporal scales of individual clouds and storms. Boundary shape is likely complex, while boundaries may relocate unpredictably and also might be directly sensed only by in-situ traverses and scanning radar thin-line signatures. The likely complexity of mesoscale BL evolution commends an effective field coordination and communication strategy. A capability is needed for FC workstation ingest and rendering of multiple data sources in near real-time to allow inference of kinematic, thermodynamic, and reflectivity boundary features. Effective field communications are needed to: (1) gather latest observations (eg. local remote and in-situ data and remote web-based products); (2) disseminate updates on subjectively analyzed boundary locations and other mesoscale weather features; (3) help coordinate sampling strategies among the various mobile field platforms.

The NCEP/Storm Prediction Center (SPC) has expressed great interest in the findings of the boundaries/CI work during IHOP. SPC is conducting a collaborative SPC-NSSL forecast experiment for May-June 2002, that in part will provide forecast support for IHOP (see "Daily IHOP Forecasting and Nowcasting Support" in Ops. Plan). Better understanding of convection initiation probability is of great interest to the SPC. It has been noted by SPC forecasters that understanding why "null events" occur is as important as understanding why deep convection initiation occurs. This underscores the importance of staying with initial targeting choices -- as long as potential exists for deep convection initiation -- to determine if CI or a null event will occur.

1.1. Convection initiation (CI)

A primary objective of mobile, ground-based sampling in IHOP is to improve understanding of surface-based boundaries and the convection initiation (CI) process in the southern U.S. plains (Fig. 1). The specific CI objectives are as follows:

- probe finescale structure of water vapor mixing ratio, virtual potential temperature, and winds along boundaries in regions of convection initiation and/or cloud/storm suppression.
- facilitate computation of air trajectories with time-spaced multi-Doppler airflow analyses;
- obtain data suitable for retrievals/assimilation and analysis of the boundary layer.

The proposed field strategy emphasizes a nesting of finescale in-situ measurements in that region of the boundary layer sampled by ground-based and airborne radars. The overarching philosophy is to obtain time series of radar-based 3-D airflow analyses and detailed in-situ measurements.

Of particular interest to the CI group are any trajectories that feed moisture up to and through the bases of developing convective clouds -- though the family of all trajectories is of interest. The 3-D airflow

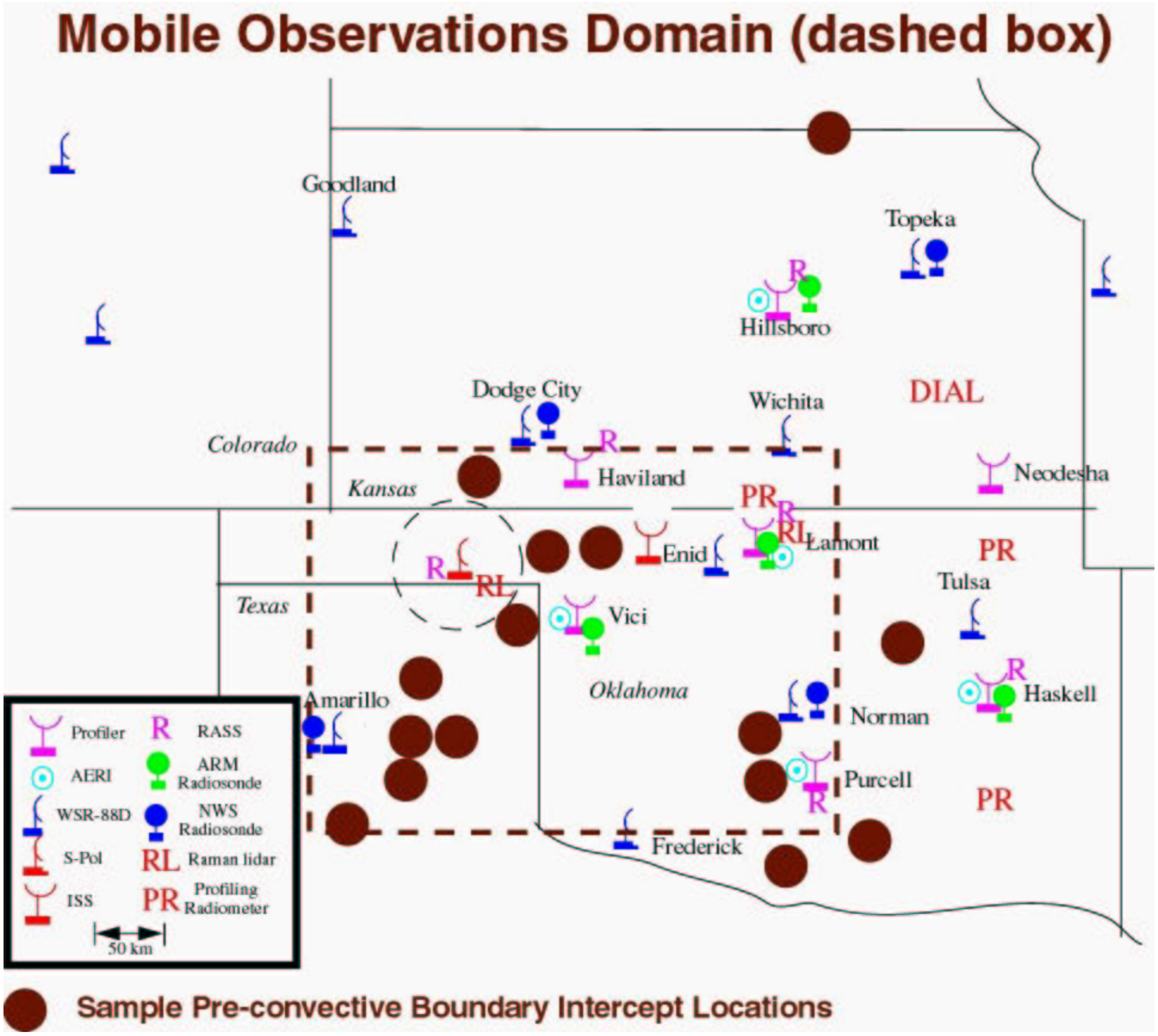


Fig. 1. The operations domain for mobile, ground-based platforms (dashed box) for the Convection Initiation (CI) study during IHOP. To illustrate past experience, dots denote intercept locations of selected slow-moving (< 5 m s^{-1}) pre-convective boundaries from the COPS-89, COPS-91, VORTEX-94, and VORTEX-95 field experiments. The types of boundaries intercepted included drylines (mainly in Texas and NW Oklahoma), stationary fronts, and decayed thunderstorm outflow boundaries.

analyses from multiple scanning ground-based and airborne radars should be sufficient to test a common argument of the CI hypotheses, namely that the character of the resolvable (small mesoscale) airflow (especially vertical motion) is a key factor in the timing and location of convection initiation. The measurement of the variability of water vapor mixing ratio in the Doppler analysis domain via DIAL lidar, profilers and other remote sensors, and in-situ sampling is a second key factor. A third key factor is the virtual potential temperature field in the BL, which may exert a primary forcing on mesoscale BL dynamics, requiring concentrated in-situ measurements from soundings, dropsondes, profilers, and aircraft traverses.

1.2. Joint ABL-CI and Sunrise BL Exercises

An additional objective of mobile, ground-based sampling in IHOP is to document the development of the convective BL and surface-generated mesoscale circulations in the vicinity of a terrain ridge or major gradient in land surface characteristics (soil moisture, land use). The Atmospheric Boundary Layer (ABL) and CI groups would use this jointly collected data set to test the hypothesis that terrain or a surface-characteristics boundary triggers a mesoscale circulation, which in turn may trigger deep convection.

Principles of the ABL-CI joint exercise are as follows. The aircraft flight pattern is a hybrid of the ABL boundary mission and the primary coordinated flight plan of CI (e.g. see "Aircraft Operations" in IHOP Ops. Plan). The patterns should be flown with respect to fixed surface features (soil-moisture boundary, ridge, land-use boundary) within close range of the mobile armada base. Flights along pre-determined (ground-located) flight tracks are desirable, but not mandatory. An acknowledged limitation is that soil-moisture boundaries cannot be precisely located. However, surface heat flux analyses can be obtained, therefore legs could be located relative to large surface heat flux gradients. The mobile ground-based armada is ideally suited to study CI in the vicinity of a quasi-stationary boundary. Therefore, the ABL aircraft measurements would be augmented with mobile ground-based observations.

The "sunrise BL" exercise will be analogous to the ABL-CI study. Mobile ground-based platforms will be deployed inside the BL scan coverage of the S-Pol radar. Data collection would commence around dawn, and would continue during the morning hours.

CHAPTER 2. Convection Initiation Hypotheses

Improved anticipation of the timing and location of convection initiation (CI) or the failure of initiation in human and numerical forecasts will represent an important step toward realizing more accurate quantitative precipitation forecasts (QPF) of warm-season convective precipitation systems. Discussions between IHOP investigators and forecasters at the NOAA/NCEP/Storm Prediction Center and several NWS Southern Region forecast offices have identified the problem of where and when deep, moist convection will initially form as a key concern for operationally predicting severe convective weather. Moreover, the skill of mesoscale model forecasts involving warm season convection may be strongly dependent on the method used to parameterize the subgrid convection (Kain and Fritsch 1992; Stensrud and Fritsch 1994).

The impact of convection initiation on the warm-season QPF process may be likened to choosing a decision point in a semi-chaotic system (Stensrud and Bao 1992), wherein persistent convection is set in motion depending on the probability of occurrence or non-occurrence of convection initiation. This convection may produce extensive cold outflows and cloud shields, as well as locally severe and disruptive weather, thus imposing significant impacts on the larger meso- and synoptic-scale weather patterns (Ziegler 1999). Increasing evidence from observational and modeling studies suggests that mesoscale forcing along boundaries with widths of order 1-10 km or less is probably critical to the initiation of convection. Hence, keys toward improving forecasts of convection are improved characterization of the mesoscale water vapor field as well as measurement of inhomogeneities and stratification of wind shear, airflow convergence, and virtual temperature in the vicinity of boundaries. Successfully anticipating or observing the formation, movement, and structure of mesoscale boundaries is also believed to be of primary importance for forecasting convection initiation.

The NSSL focus on boundaries and convection initiation is within the context of the broader IHOP objectives (e.g. see "set of testable, refutable science hypotheses" at http://www.atd.ucar.edu/dir_off/projects/2002/IHOPci/index.html). There are three main sub-themes or questions posed by the IHOP convection initiation group: kinematic controls, moisture controls, and dynamical forcing. These sub-themes, the assembled hypotheses of the IHOP convection initiation group, and a list of seminal references on this topic are provided on the IHOP web site.

We hypothesize that convection initiation requires mesoscale lift both deep and broad enough for rising, moist boundary layer air to achieve its Lifting Condensation Level (LCL) and Level of Free Convection (LFC) before being detrained from the mesoscale updraft by ambient vertical shear of the horizontal wind. In the following two sections, we present our own specific hypotheses regarding kinematic controls and dynamical forcing to be tested according to the data and analysis procedures proposed herein. Each objective will be discussed in terms of the process to be studied, a testable and refutable hypothesis, the data required for the test, and the conditions for refutation. We believe that this level of detail is essential to elucidate the goals and techniques of our research. The NSSL contribution to IHOP is based on a *collaborative NSF research project* involving teams at the University of Oklahoma (School of Meteorology and CIMMS) and the Pennsylvania State University (PSU). Thus, the following hypotheses have been contributed and debated by the OU/NSF Principal Investigators (CZ and ER) and Professor Paul Markowski at PSU (i.e. the collaborating researcher).

2.1. Hypotheses related to kinematic controls

OBJECTIVE 1: *Effect of vortices on vertical motion, water vapor mixing ratio, virtual potential temperature, and convection initiation (Rasmussen, Ziegler)*

PROCESS TO BE STUDIED: High-resolution surface data recently have been obtained from a mobile mesonet that shows that vortices exist on the Denver Convergence Zone and drylines with scales of 1000 m or less. Our observations of the deformation of water vapor mixing ratio gradients by embedded vortices suggest that these vortices transport near-ground water vapor horizontally. Visual observations show there may be an association between cumulus growth and the existence of a vortex, suggesting that vortices also lift water vapor. If enhanced convergence results from vortex interaction with the boundary, lifting of air parcels in vortices may result in locally increasing the water vapor mixing ratio, the depth of the moist layer, and the probability of convection initiation. Theoretical considerations suggest that the vortices may be areas of reduced turbulence and entrainment of drier air, thus further protecting ascending parcels from dilution.

HYPOTHESIS: Vortices along boundaries are associated with local maxima in vertical velocity, water vapor mixing ratio, virtual potential temperature, and frequency of convection initiation; have similar structure aloft as at the ground; and are connected to the boundary through its depth.

TEST: Prior to the development of deep convection, sample the kinematic structure of the boundary within the full depth of the boundary layer with clear-air Doppler radar (WSR-88D, mobile ground-based, ELDORA) to identify a boundary layer convergence line with vortices. Determine the thermodynamic structure of the boundary within the full depth of the boundary layer with observations from fixed and mobile mesonet, dropsonde, mobile sounding, mobile profiler, aircraft traverse, ground-based and airborne DIAL water vapor lidar, and mobile ground-based water vapor radiometer. Monitor for the development of deep convection with radars, satellite, and video photogrammetry. Doppler analysis determines mesoscale circulations. Airborne DIAL, profiler, and in-situ measurements map water vapor mixing ratio distribution. Examine temporal-spatial correlation between vortices, convergence and mesoscale updrafts, and positive humidity anomalies. Compare remote and in-situ measurements with thermodynamic fields retrieved from dual-Doppler wind syntheses.

REFUTE: Convection does not preferentially form in vortices. No correlation exists between locally convergent mesoscale circulations, vortices, and moist pockets. Ground-detected vortices weaken/disappear with height below the boundary top/inversion. Virtual temperature perturbations aloft are not correlated with the existence of ground-detected vortices.

OBJECTIVE 2: *Effect of lift and parcel humidity along mesoscale boundaries on convection initiation (Ziegler, Rasmussen)*

PROCESS TO BE STUDIED: A modeling study of dryline convection initiation determined that deep convective clouds may develop along the boundary at locations with strong, deep mesoscale updrafts given sufficient ambient water vapor (Ziegler et al. 1997). The predominant scale of lifting in those studies is mesoscale (~ 1-10 km length scale), that is, greater than the short length scales commonly associated with turbulent mixing. A study by Ziegler and Rasmussen (1998) demonstrated that cumulus cloud development is favored if the depth of the convergent inflow to the mesoscale updraft (i.e. level of non-divergence or maximum updraft) exceeds the Level of Free Convection (LFC). ZR also demonstrated that the height of the maximum updraft could be equated to the BL depth for scaling purposes. ZR suggested an analogous relationship between the depth of lifting, the Lifting Condensation Level (LCL), and the development of shallow cumulus clouds. ZR noted that any small-scale turbulent detrainment of moisture from the mesoscale updraft would be offset by the convergent motions below the level of non-divergence -- rendering the maximum updraft height a robust scaling parameter even in the presence of mixing. The likelihood of convection initiation may be generalized by a simple combination of local boundary layer parameters representing the length and time scales and the magnitudes of lift and water vapor content along the mesoscale boundary (Ziegler and Rasmussen 1998).

HYPOTHESIS: Convection initiation requires deep mesoscale boundary layer convergence, subject to the constraints that updraft width exceeds the maximum local advective length scale and updraft depth exceeds the local Lifting Condensation Level (LCL) and Level of Free Convection (LFC). This hypothesis may be expressed by the following joint conditions on the dimensionless ratios of the latter length and depth scales: (1) For SHALLOW cumulus convection (i.e. Cu not meeting the CI criterion), $R(LCL) = H/LCL > 1$ and $R^*(LCL) = WxL/UxLCL > 1$; (2) For DEEP cumulus convection, $R(LFC) = H/LFC > 1$ and $R^*(LFC) = WxL/UxLFC > 1$; where by definition U = flow speed across updraft, W = peak updraft speed, L = updraft width, and H = height of peak updraft.

TEST: Use mobile ground-based and airborne pseudo-dual Doppler radar clear air measurements to estimate 4-D mesoscale airflow circulations in the CBL. Estimate surface-based and boundary layer

parcel LCL and LFC using observations from fixed and mobile mesonet, dropsonde, mobile sounding, mobile profiler, and aircraft traverse. Measure cloud location and cloud base height with digital ground-based stereo and airborne cloud photogrammetry, visible satellite imagery, and airborne WCR data. Use cloud/mesoscale retrieval and data assimilation to blend above observations with high-resolution DIAL water vapor measurements, to estimate the 3-D virtual temperature and absolute humidity field and compute spatially variable LCL and LFC. Determine parameters U, W, L, H, LCL, and LFC at location of mesoscale updraft cores. Results will be stratified by boundary type, stability, and shear to evaluate predictability in a range of environments. Stratify cases with or without shallow/deep convection by respective R and R* values.
REFUTE: **Shallow cumulus**: occurs with R(LCL) < 1, or R*(LCL) < 1, or both; or does not occur despite R(LCL) > 1 and R*(LCL) > 1. **Deep convection**: occurs with R(LFC) < 1, or R*(LFC) < 1, or both; or does not occur despite R(LFC) > 1 and R*(LFC) > 1.

OBJECTIVE 3: *Location of CI relative to baroclinity of boundaries (Markowski)*
PROCESS TO BE STUDIED: This objective addresses the displacement of the location of convection initiation relative to the surface boundaries as a function of the slope of the kinematic or thermal boundary. Boundaries with a shallow slope (i.e. large baroclinity) may be associated with large horizontal parcel excursions en route to the level of free convection, if parcel trajectories approximately remain within isentropic surfaces. Conversely, parcels lifted by a steeply sloped boundary may have small horizontal excursions en route to the level of free convection. It is expected that slope is inversely dependent on the magnitude of the baroclinity or the temperature difference across the boundary. Following Ziegler and Rasmussen (1998), convection initiation is not expected to occur if parcels do not achieve their level of free convection during the finite period of parcel upglide.
HYPOTHESIS: Given the occurrence of convection initiation on the cold side of a thermal boundary, the distance of convection initiation to the cold air side of the surface boundary will increase as the baroclinity associated with the boundary increases.
TEST: Assess the baroclinity of the thermal boundary using vertically spaced aircraft traverses, dropsonde, mobile sounding data, and thermodynamic retrievals from Doppler wind syntheses. Determine the (baroclinity-related) slope of the thermal boundary aloft using mobile ground-based and airborne Doppler radar, dropsonde, DLR DIAL and NOAA HRDL (and possibly SABL and downward-pointing Leandre II). Determine the sign and magnitude of the correlation between the baroclinity strength and the distance from the boundary location at the surface to the location of CI, stratifying data according to the level of free convection.
REFUTE: Analyses of baroclinity strength and the distance from the boundary location at the surface to the location of convection initiation are uncorrelated or negatively correlated.

2.2. Hypotheses related to dynamical forcing

OBJECTIVE 4: *Generation of secondary circulations near mesoscale boundaries (Ziegler, Markowski)*
PROCESS TO BE STUDIED: Frontal zones are regions of baroclinity by definition, but baroclinity is also commonly observed along drylines and outflow boundaries (e.g., Goff 1976; Mueller and Carbone 1987; Ziegler and Hane 1993; Ziegler and Rasmussen 1998; Atkins et al. 1998). Mesoscale modeling studies have documented the presence of horizontal virtual potential temperature gradients in the vicinity of drylines (eg. Ziegler et al. 1995; Ziegler et al. 1997). These horizontal virtual density gradients may be present at sunrise, and are modified by horizontal transport and surface heating patterns during the daytime. A combination of solenoidal and frontogenetic forcing may increase horizontal thermal gradients and vertical wind shear along boundaries. Increases in boundary layer convergence may persist during the transition from a convective boundary layer to an incipient stable boundary layer during the afternoon-evening period, as a result of persisting horizontal thermal gradients and solenoids. This evolution leads to increased moisture convergence associated with moisture transport, and an increasing probability of convection initiation.

HYPOTHESIS: Vertical wind shear normal to (i.e. horizontal vorticity parallel to) and within the cool side of a mesoscale baroclinic boundary increases during the afternoon and evening from the action of a thermal solenoid, which induces a thermally direct secondary circulation. The secondary circulation leads to augmented moisture convergence and moisture depth, which may promote CI.
TEST: Evaluate the horizontal vorticity component parallel to the mesoscale thermal boundary with ground-based mobile multiple-Doppler and airborne pseudo-dual Doppler analysis of the 3-D boundary layer airflow. Blend dynamically retrieved virtual temperature with mobile mesonet, dropsonde, mobile sounding, mobile profiler, aircraft traverse, and high-resolution ground-based and airborne DIAL water vapor measurements to determine the solenoid field in the boundary layer. Evaluate correlation of changes in the horizontal vorticity component parallel to the boundary and the magnitude of the horizontal buoyancy gradient normal to the boundary.
REFUTE: Locally increasing horizontal vorticity cannot be correlated with strength of baroclinity via the horizontal vorticity equation.

OBJECTIVE 5: *Generation of buoyancy forcing along boundaries (Ziegler)*
PROCESS TO BE STUDIED: Observational studies of drylines have suggested that local maxima of virtual temperature may develop from the surface through the lowest 100-200 m of the CBL in a region of strong horizontal convergence (Ziegler and Hane 1993; Atkins et al, 1998; Ziegler and Rasmussen 1998). Modeling studies of drylines and their colocated mesoscale updrafts have documented the presence of enhanced horizontal vorticity solenoidal forcing on the updraft flank in the lower CBL (Ziegler et al. 1995) and virtual potential temperature plumes in the updraft cores (Ziegler et al. 1997). This effect may provide a source of thermal buoyancy for invigorating the mesoscale updraft.
HYPOTHESIS: The unstable low-level stratification in the CBL is tilted into the horizontal by convergent circulations associated with mesoscale updrafts and boundaries, deforming and locally deepening the unstable layer.
TEST: Evaluate the 3-D airflow across a mesoscale boundary in the CBL with ground-based mobile multiple-Doppler and airborne ELDORA and WCR pseudo-dual Doppler analysis. Blend dynamically retrieved and measured virtual potential temperature from mobile mesonet, dropsonde, mobile sounding, mobile profiler, and aircraft traverse observations. Compute kinematic frontogenesis terms, and use a kinematic continuity retrieval model with an insulated lower boundary to compute the virtual potential temperature field across the low-level mesoscale updraft. Compare kinematically modeled and observed virtual potential temperature fields with kinematic frontogenesis terms.
REFUTE: Neither a deepening of the unstable stratification nor a local maximum of virtual potential temperature are observed in low-levels of mesoscale updrafts in the CBL. Equivalently, kinematically modeled tilting frontogenesis does not produce either a deepening of the unstable stratification or a local maximum of virtual potential temperature in low-levels of mesoscale updrafts in the CBL.

OBJECTIVE 6: *Dissipation rate of horizontal vorticity near boundaries (Markowski)*
PROCESS TO BE STUDIED: This objective addresses the longevity of secondary circulations near boundaries as influenced by turbulent dissipation. Horizontal vorticity generated by horizontal density gradients "outlives" the density gradients by a time scale dictated by the turbulent dissipation of the vorticity. For example, an outflow boundary initially may be associated with a large thermal gradient, which baroclinically generates primarily horizontal vorticity. Both the thermal boundary and the solenoid field are usually approximately two-dimensional (i.e. thermal gradient normal to quasi-linear boundary). Over time, the thermal gradient associated with the outflow boundary tends to weaken owing to modification of the cold air mass; however, there is some evidence that the dissipation of the baroclinic horizontal vorticity (Dutton 1986) has a time scale of a few hours (Markowski et al. 1998). Thus, the effects of solenoids may be important to CI even after the solenoids themselves have diminished. The vorticity dissipation rate (for the total horizontal vorticity, which includes both the baroclinic horizontal vorticity described above as well as the barotropic horizontal vorticity) is expected to vary according to the static stability (which is associated with buoyant production of turbulence) and ambient vertical wind

shear (which is associated with mechanical production of turbulence). In cases in which the density contrast across a boundary has dissipated, how long does the baroclinic vorticity persist, and how does this timescale vary?

HYPOTHESIS: The horizontal vorticity dissipation rate increases as the mean static stability decreases and the mean vertical wind shear increases.

TEST: Determine the low-level static stability from mobile soundings, dropsondes, and vertically spaced UAV and aircraft traverses. Determine horizontal vorticity dissipation rate as a residual from measurements of the local vorticity tendency and barotropic vorticity terms (as diagnosed by three-dimensional syntheses of mobile ground-based and airborne Doppler radar data), and baroclinic vorticity generation (as diagnosed from dropsondes, mobile soundings, and vertically spaced aircraft traverses). Determine the mean vertical wind shear from dropsondes, mobile soundings, WCR, multiple-Doppler radar wind syntheses, and mobile wind profiler data. Determine correlation of horizontal vorticity dissipation rates with static stability and wind shear.

REFUTE: The dissipation rates of horizontal vorticity are uncorrelated or positively correlated with low-level static stability, and uncorrelated or negatively correlated with mean vertical wind shear measurements.

CHAPTER 3. Field Strategy

The armada would obtain closely coordinated measurements of boundaries under conditions hypothesized to be conducive to convection initiation. Experience indicates that the best weather targets tend to be broadly distributed through the IHOP domain in the May-June time frame (Fig. 1). Plans call for the following mobile ground-based data collection platforms to be deployed by NSSL during IHOP:

- NOAA/NSSL Field Coordination (FC) vehicle;
- NSSL/OU mobile mesonets (MM);
- 5-cm SMART Doppler radar SR-1 (co-developed and shared by NSSL, OU, Texas A & M, and Texas Tech);
- NOAA/NSSL mobile CLASS sounding system (CLASS);
- NOAA/NSSL digital photography vehicle (CAM).

Additionally, a prototype CU all-weather RPV (i.e. extremely low altitude ~ 100 ft, "airborne mesonet") might also be operated in very close coordination with the NSSL mobile facilities on a highly intermittent, test basis. Chapter 4 describes the NSSL and other ground-based mobile facilities in greater detail.

Additional mobile ground-based facilities will be operated by other institutions during IHOP in close cooperation with the NSSL-operated facilities:

- Univ. of Oklahoma and Univ. of Connecticut 3-cm "Doppler-On-Wheels" (DOW) Doppler radars;
- National Center for Atmospheric Research mobile GLASS sounding systems;
- University of Alabama (Huntsville) Mobile Integrated Profiling System;
- Desert Research Institute Mobile Microwave Radiometer;
- 3-mm radar deployed by the University of Oklahoma.

A group of research aircraft would also obtain measurements of boundaries in close coordination with the ground-based armada. The CI group has requested the deployment of the following aircraft platforms:

- Naval Research Laboratory P-3 with ELDORA and DIAL;
- University of Wyoming King Air (UWKA) with WCR;
- DLR Falcon with downward-pointing DIAL;
- Flight International, Inc. Learjet dropsonde aircraft;
- National Aeronautics and Space Administration DC-8;
- National Aeronautics and Space Administration Proteus.

Details of the aircraft operations are described below and also in Chapter 6 ("Aircraft operations") of the IHOP Operations Plan.

3.1. Selection of IHOP mission and target IOR

During IHOP, a daily "early IHOP weather briefing" will be conducted at NSSL at 0900 LDT. This briefing will usually be conducted by the NSSL/SPC experimental forecast team, and will involve a group of key IHOP leaders and PIs. The outcomes of this meeting will be a GO or NO-GO decision for mobile ground-based operations for the current day (Day 1). A notification e-mail message will contain only two items so that it can be prepared quickly. It will contain the GO/NO-GO status, and it will contain one line regarding the possibility of an overnight stay in the field (NO/POSSIBLE/YES). The notification message will also be made available on a phone answering machine. Participants that do not have access to e-mail might want to make arrangements to call another participant who does, because the phone answering machine at NSSL will be heavily utilized. A later e-mail message may be issued which explains the reasons for a NO-GO decision. The reasoning behind a GO decision will be explained at the daily weather briefing, and during a radio (main VHF channel) briefing at departure time.

A key to mobile ground-based observations will be the selection of and deployment by the armada inside a target "Intensive Observing Region", or IOR, which in turn is to be located somewhere within the IHOP

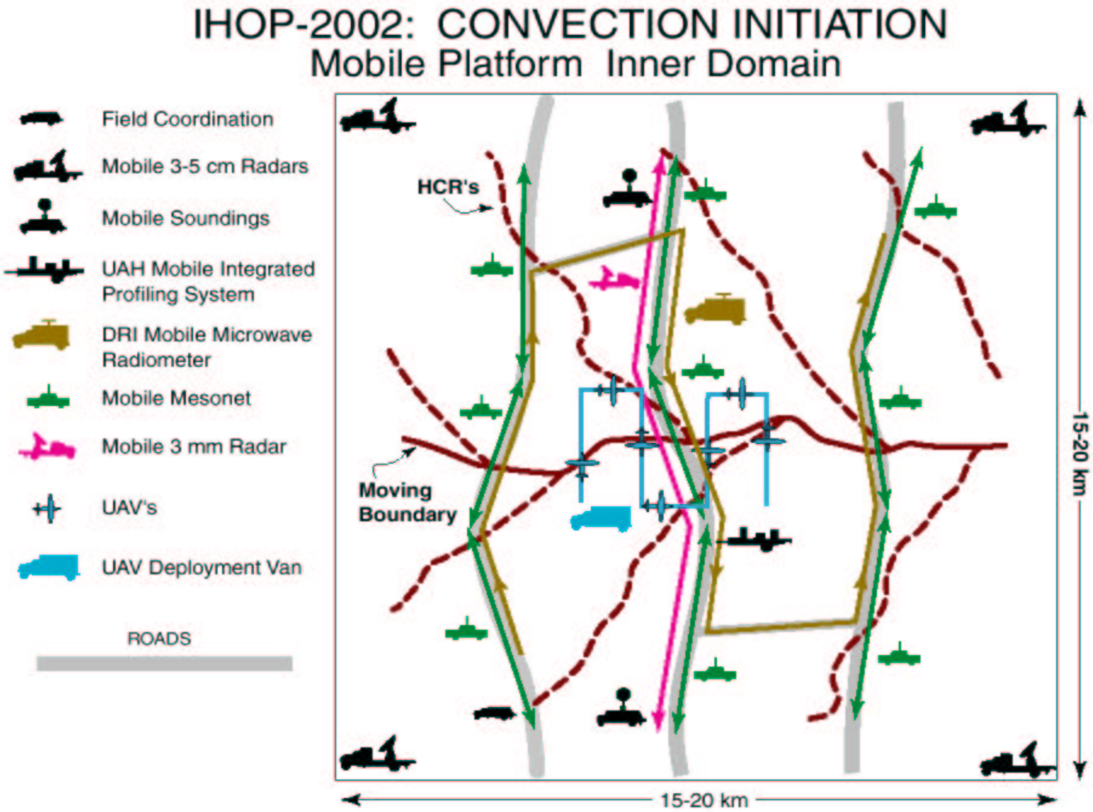


Fig. 2. Schematic depiction of the proposed deployment of mobile, ground-based platforms in the Intensive Observing region (IOR) for the Convection Initiation (CI) study during IHOP. Mobile radars (at corners of IOR) and research aircraft legs (see also Fig. 3) provide complementary observational coverage of the IOR and its immediate mesoscale environment.

mobile observing domain (Fig. 1). The IOR would be nested inside the Doppler lobe and would straddle the target boundary (Fig. 2). The IOR would have an along-boundary dimension of about 20 km. As described below, a preliminary target IOR will be selected for initial deployment. This initial IOR may subsequently be modified slightly during the afternoon and evening to account for local changes of the BL that could not be anticipated during the initial selection process.

A final ground-based mobile operations decision for the day (i.e. "Day 1") will be made by 0930 LDT. The decision will be posted immediately on the Internet using a short e-mail message to that week's NSSL participants, and will be made available on a phone answering machine. Participants that do not have access to e-mail might want to make arrangements to call another participant who does, because the phone answering machine at NSSL will be heavily utilized. The 0930 LDT decision will be one of the following: GO or NO-GO. If the status is GO, all participants should be at NSSL by 0930 LDT; the ground teams will depart at 1000 LDT. If the status is NO-GO, there will be no ground-based mobile operations.

Ordinarily, a STANDBY decision will be used for IHOP mobile ground-based operations in only one circumstance, the possibility of Day 2 operations. On the other hand, STANDBY decisions would not be feasible for Day 1 operations as in several past experiments. The reason is that the armada would need to deploy not later than 1000 LDT to reach a CI target by early afternoon, assuming a ferry time of 4 hours.

Therefore, delaying a CI deployment decision may be tantamount to making a NO-GO decision. The ground-based mobile support for ABL-CI missions has an even stricter lead time requirement, as ABL missions would be conducted from sunrise to 1300 LT. Therefore, in IHOP there will only be a possible STANDBY decision for the case of overnight trips to support CI or ABL-CI missions on Day 2.

The 0930 LDT operations decision would be made in the following manner. If 1200 UTC soundings, morning analyses, and the previous evening's model data indicate a good chance for new, isolated convection within about four hours of Norman, the operations decision will probably be GO, and we will get to the field early to conduct the CI experiment. If it appears there is a reasonable chance of new, isolated convection beyond about 4-5 hours drive time, the decision could be either GO or NO/GO. In either event, it may ultimately be decided to abort and return to base if the forecasters determine later that conditions clearly no longer look favorable.

Prior to deployment of ground-based mobile platforms in mid-morning, the nowcaster should develop a strong sense of the exact location and nature of boundaries. If at all possible, the ground teams should be deployed and on station well prior to the development of the first clouds on visible imagery. Both prior to and after deployment, boundaries should be identified based on wind shifts, WSR-88D finelines, and virtual temperature and humidity contrasts if these are starting to develop. The overall highest priority for CI and ABL-CI mission nowcast support is to provide the FC vehicle with any needed refinements of the target IOR based on the latest weather information.

A proactive decision process involving the Convection Initiation PIs and IHOP leaders will be employed to determine the appropriate IOR location. The FC vehicle would then assist and facilitate the closely coordinated mobile field observations by the ground-based armada and aircraft. Locations and modes of operation of the various mobile platforms would be coordinated following the predetermined, IOR-relative observing strategies as described below. The following subsections describe in detail the deployment modes and strategies of the mobile ground-based armada.

3.2. Preparation for departure (PREP)

All NSSL armada participants should assemble at the NSSL/NOF building. This is a one-story, red brick structure with two large garage doors immediately south of the main NSSL building. The IHOP cars and CLASS vehicle will typically be located overnight in the fenced parking area in the rear (west) of the NOF, while the SMART radar and FC vehicle would be garaged inside the NOF garage bays. Vehicle preparation for departure will take place in and around the NOF.

During PREP, the NSSL participants will make sure their vehicles and equipment are ready for the day's operations, with sufficient supplies for one additional day and one overnight. Vehicles must be refueled at the end of the previous mission, and the oil and engine should be visually inspected prior to mission departures. Do not run auxiliary equipment (especially the VHF transceivers) without the engine running to avoid draining the vehicle battery. The team leader is responsible for going over the appropriate pre-departure checklist for the vehicle. Checklists for each vehicle type are in preparation and will be available near the beginning of the IHOP field phase.

Calibration checks will be performed on the mobile mesonet equipment in the NOF parking area (See "3.3. Mobile Mesonets"). The previous day's mobile mesonet data will be inspected by the quality assurance manager prior to departure for gross errors using a graphing program.

3.3. Travel to target (TRAVEL)

This activity will commence when all preparations for field work are complete. NSSL teams will ordinarily depart from their base at the same time and travel together to the target region (NSSL vehicles staying within ~10 miles of the FC vehicle), allowing for refueling stops. All NSSL vehicles should leave the NOF building with full tanks. All vehicles should top their tanks at refueling stops when necessary and appropriate. We may attempt to refuel prior to commencing field data collection operations, if necessary and possible. All participants should attend to personal needs during the refueling stops; it will not be feasible for vehicles to drop out of the caravan for more than a few minutes to accommodate personal needs. If vehicle maintenance problems occur, the team leader should call a special toll-free phone number for assistance.

The IHOP nowcasters will communicate with IHOP field facilities via the mobile field coordination (FC) vehicle, passing on and receiving mesoscale weather information and facilities updates. The refined Day 1 target IORs (based on the Day 1 Forecast #2), the Day 2 outlook, and the tentative Day 2 mission status will be relayed from IHOP staff nowcasters to the mobile field coordinators and aircraft.

In the early stages when the field teams are not yet in position collecting data, the boundary might be somewhat diffuse. In the event of a diffuse or rapidly evolving boundary, the nowcaster needs to monitor closely that the boundary is not sharpening up at some location outside the current IOR. Such rapid evolution might require the field teams to quickly re-deploy to a newly identified target IOR. Early warning is essential due to the limited maximum speed of ground teams.

The travel window duration depends on the required travel time from the morning departure site to the target area. During the travel window, the NOC forecasters will be successively refining the forecast of boundary locations and the convection initiation area and time. As the forecasts are refined, the route plan will be refined.

TRAVEL activities will include 1-sec mobile mesonet data collection by all MM teams. In addition, certain preparations for the pre-convective BL sampling phase can be conducted in the NSSL vehicles as they caravan toward the target area (e.g. digital cameras, documentation preparation, VHF-FM transmission checks and FreeWave radio data tests for MMs close to FC). Briefings will be broadcast on the VHF radio as required (e.g. when new information is received from the NOC).

3.4. Single Boundary (CI1)

All CI experiments will follow the design of experiment CI1, regardless of whether the boundary that is expected to initiate convection is a warm front, stationary front, a dryline, or a decayed thunderstorm outflow. Target boundaries must be slow-moving (i.e. < 5 m s^{-1}) to enable ground-based mobile sampling by the armada. Experiment CI1 will be conducted when a boundary is expected to play a role in the initiation of deep convection, regardless of the anticipated storm type. It will be conducted on a target-of-opportunity basis when the field team caravan arrives in a target area prior to the development of deep towering cumuli (TCU). The observations will collectively be used to assess the morphology of the boundary and to understand how it propagates, how BL stratification and forcing alters the local vertical wind profile, and how the changes in BL structure and moisture transport control the initiation of storms.

Ground-based mobile Doppler radars and the P-3 with ELDORA will obtain clear air velocity data within the IOR. The P-3 DIAL will simultaneously map horizontal water vapor mixing ratio variations along and ~5-6 km out from the P-3 flight track. The UWKA will obtain in-situ data via traverses and ascent-descent soundings, as well as remote airflow and reflectivity data from the Wyoming Cloud Radar (WCR). The DLR Falcon will obtain downward-pointing DIAL data, while a dropsonde aircraft will obtain additional soundings. For more details of aircraft deployment relative to the ground-based radars and the IOR, see section 4.8 of this manual.

Three mobile ground-based sounding systems will be deployed to obtain profiles at a space scale of about 30 km, two on the moist (most unstable) side and one on the dry (least unstable) side of the boundary. One of the moist-side mobile labs will be positioned close to the surface boundary, while the other moist-side mobile lab will obtain soundings around the center of multiple ground-based radar coverage. Three MM teams will make continuous transects of the boundary, while groups of three additional MMs will make traverses in the airmasses on either side of the boundary, as directed by the FC, to measure evolution of surface conditions. Both along- and across boundary variability of surface weather conditions will be assessed.

Prior to the arrival of the aircraft and surface teams at the boundary, its position will be assessed using conventional data at the NOC. A target location for the central point of the experiment will be chosen in discussions between FC and NOC. This target point should be the intersection of the boundary with a major highway oriented roughly normal to the boundary, as close as possible to the forecasted centroid of the maximum probability of convection initiation. Ideally, there will be three or more approximately parallel roads normal to the boundary and spanning the IOR, on which surface teams can operate to collect data. If the surface teams arrive first, one or two teams will be sent ahead to pinpoint the location of the boundary and report it to FC and NOC. Once this point is found, the rest of the armada will be deployed on data gathering missions. If the aircraft arrive first, the P-3 should perform its first low-level transect over the chosen target highway, and report the location of the boundary to FC and NOC.

Once the CI teams are collecting data on a boundary that can be readily identified and monitored through real-time field data, the emphasis of IHOP nowcasting should shift toward carefully monitoring the mesoscale environment just beyond the current IOR. The nowcaster should monitor areas adjacent to the IOR for new boundary formation, an increasing probability of CI, the motion of secondary boundaries toward the current IOR, the movement of larger-scale lower tropospheric mesoscale ascent toward or away from the current IOR, or other significant factors. Given a clear need to abandon the current IOR, the highest nowcasting priority should be to promptly advise field teams regarding a new target IOR (see "REDEPLOY" below).

3.5. Intersecting dryline-front or dryline-decayed outflow (CI2)

This experiment would be conducted in a case where storms are expected to initiate near the intersection of low-level mesoscale and/or synoptic boundaries. The primary goal of this experiment is to document the morphology of lifting of the dryline by the intersecting outflow/front and the effect of dryline lifting on convection initiation. A secondary goal is to monitor the morphology and CI process along the surface-based boundaries in immediate proximity to the point of intersection. In principle, while the intersecting surface-based boundaries might themselves be too shallow for CI, the DL and associated secondary circulation may be lifted (occluded) sufficiently along the elevated frontal surface for the combined lift to initiate convection.

The field strategy of experiment CI2 is exactly analogous to that of CI1, except that some leg positions will be adapted slightly to allow sampling of all three airmasses involved. In particular, the elongated P-3 box pattern will be oriented along the dryline, with one end of the box extending into the cold air along the projection of the occluded (elevated) dryline. The UWKA stacked traverse will be directed across the expected location of the elevated dryline, approximately 10 km into the cold air from the point of surface occlusion. The surface teams will perform transects beneath the UWKA, since that is the area deemed most likely to contain elevated CI. Dropsondes and DLR Falcon legs will be directed along/above the UWKA stacks.

The first teams on site will be used to refine the triple point location information provided by the NOC. Since the front that features the strongest thermal contrast (e.g. the ~ east-west oriented stationary front, warm front, or outflow boundary) is typically moving along the intersecting (occluded) dryline, the point of occlusion or "triple point" is also moving. The IOR should be centered along the dryline slightly ahead of the moving triple point, or alternatively would be centered on a stationary triple point.

3.6. Joint ABL-CI (ABL-CI) and sunrise BL exercises

A suitable mission day would have fair-weather conditions, possibly with light winds, yet with at least marginal potential for the outbreak of general or airmass-type thunderstorms. The ABL flight patterns from the UWKA are to be along one leg orientation at multiple heights (i.e. stack), and would be repeated. The leg would be normal to the boundary and penetrate it. The leg length must be adequate to obtain flux estimates (including leg length on either side of a boundary). To conserve flight time, only boundary-normal legs would be flown. The location of the ABL-CI pattern would preferably be along one of the ABL group's pre-located flight transects, but not unless there is some type of boundary or strong surface contrast (land use, soil moisture, terrain) along a transect. In the case that a boundary is targeted, two back-to-back 3.5-h sorties may be flown if the boundary persists. NSSL teams may preposition during Day 1 near the eastern Oklahoma Panhandle for Day 2 missions around the S-Pol or Homestead fixed ground-based IHOP facilities.

The smaller-scale CI measurements (mobile ground armada in the Inner CI Domain) are blended with UWKA and DLR Falcon gradient- or boundary-crossing legs. The UWKA pattern includes long, DLR Falcon nadir DIAL traverses (~100-200 km or 60-120 nm) and pre-selected UWKA flight tracks (order 50 km or 30 nm long). The UWKA repeats a stacked traverse, between 1.5 Z_i (allowing WCR dual-Doppler synthesis in the vertical plane below the UWKA) and as close as possible to the ground (~ 30-100 m). In this hybrid mission the NRL-P3 documents along-line variability of airflow (ELDORA) and water vapor (LEANDRE-II DIAL). Repeated horizontal and vertical DIAL and UWKA flights along the same tracks give us understanding of the persistence of these features over time, plus a larger-scale spatial context for the mobile mesonet traverses, soundings, and other mobile ground-based instruments in the IOR. If a UAV were participating, it would be flown away from the low-level heavy aircraft legs.

As part of the site survey prior to IHOP, we will look for potential flight tracks with respect to land-use and terrain boundaries, especially near ground facilities (e.g., S-Pol radar and Homestead sites in SE Oklahoma Panhandle). Contiguity to locations of surface-based instrumentation, though desirable, is not mandatory.

3.7. Redeployment to new target boundary/IOR (REDEPLOY)

The REDEPLOY activity will be used to relocate the armada to follow a moving target boundary or to choose a new target boundary in proximity to the previous target. A decision to REDEPLOY would be arrived at via a proactive decision process involving the Convection Initiation PIs and NOC nowcasters. To maximize the temporal continuity of 3-D data collection, REDEPLOY should be conducted only over relatively short distances and only when absolutely necessary. The REDEPLOY activity would be accomplished in the following sequence:

- determine new IOR location along new target boundary. Any new IOR candidate should be within a roughly 1/2-hour drive at 55 mph for the armada (~ 40 km or 2 x IOR width). This would ideally commute to less than a ~ 1 hour break in data collection.
- relocate FC, radars, and other ground-based mobile platforms toward new target boundary, and re-establish coordinated data collection on new target boundary.
- aircraft would redeploy to new IOR center point and boundary orientation (if different), allowing time for ground-based mobile facilities to initiate REDEPLOY.

Possible reasons for conducting REDEPLOY are as follows:

- the current target boundary decays (e.g. moist BL east of DL "mixes out").

- the current target boundary displays overwhelming evidence it may not support CI (e.g. large lid or deep dry ERL for surface-based CI).
- a stronger boundary believed to have much greater CI potential (e.g. stronger surface moisture convergence, deeper BL moisture, cumulus cloud line) develops or moves within ~40 km of the current IOR and target boundary.

A REDEPLOY would be facilitated by VHF broadcast coordination from the FC. If possible, all of the field teams should be brought into close proximity to the FC prior to effecting a REDEPLOY. For example, VHF radio range is less when the FC is moving than when it is fixed on elevated terrain with the 10 m RF mast deployed.

At the beginning of REDEPLOY, the FC will give instructions to each field team regarding the new target boundary location and orientation, the new IOR centroid, and the road/position for each team to begin sampling. Team leaders would be responsible for choosing the fastest route to relocate their platform into its assigned position and operating mode relative to the new IOR.

REDEPLOY may also be used to re-establish field coordination if a major failure in communications or logistics has caused the loss of coordination.

3.8. Debrief (DEBRIEF)

Mobile field operations in support of IHOP may be terminated if no acceptable target boundaries or surface gradients exist. A proactive decision to terminate field operations would be made through consultation of the Convection Initiation PIs and IHOP leaders. After the cessation of activities, the DEBRIEF activity may commence.

Ideally, the teams would reform a caravan and would be polled by FC via the VHF radio. Teams could report any technical or logistical problems they encountered, and could note any meteorological observations they think will be of interest to all participants. The FC will log this information. If a CI, ABL-CI, or sunrise BL operation is planned for Day 2 in that vicinity, overnight accommodations would be arranged.

3.9. Check-in (CHECK-IN)

NSSL mobile ground-based teams should complete data backups for each day's operations as soon as possible during the drive home after completing a mission. The NSSL PIs and the technicians for the various platforms have worked out data archival procedures unique to each platform. Team leaders should be responsible for data until it is turned in to the IHOP Data Manager. Procedures for archiving and turning in the data sets for each mission will be provided for each team in a form separate from this NSSL Operators Manual.

All NSSL vehicles should be safely parked and locked over night. For NSSL-operated facilities returning to Norman, vehicles should be parked at the NOF building. Special parking areas are set aside for NSSL-IHOP vehicles as previously indicated, either inside the chain-link fence or inside the NOF garage bays. Instructions for properly switching off power to instrumentation will be provided for each team in a form separate from this NSSL Operators Manual.

3.10. Adjunct field activity: Initiated convection in IOR

Situations may arise during IHOP in which severe storms develop either within or outside of the target IOR, and various PIs may call for mobile data collection on these storms. There may even be situation wherein no clouds develop in the IOR, but severe storms develop and are visible to IHOP ground teams outside the IOR but at a range of 1 hour driving time or greater. It will be the general policy of the lead

NSSL principle investigator (CZ) and the NSSL co-principle investigator (ER) that storm intercept activities, defined herein as "pursuit of storms beyond the pre-convective target IOR for storm data collection", will not be conducted by NSSL mobile facilities as part of IHOP. Data gathering by IHOP mobile platforms toward boundaries/CI mission objectives should not be interrupted or otherwise terminated for the purpose of intercepting severe storms or other targets outside the current IOR.

However, some mobile ground-based sampling may feasibly be conducted on any developing storms that have initiated within the confines of the IOR. As one example, volume scanning by mobile ground-based radars could be continued on storms and their mesoscale BL environment after the complete initiation cycle of those storms has been observed. As a second example, the boundaries/CI mission of the day may be terminated if outflows from neighboring storms enter the target IOR. Any adjunct storm data collection should not be undertaken until the IHOP boundaries/CI mission profile has officially been terminated for the day. Given the possibility of Day 2 operations, the inherent lack of safety of ground-based mobile operations at night, and the inability to visually distinguish convective cloud features after dark, adjunct data collection activities should be curtailed after sunset.

A proactive strategic discussion will be conducted between the FC, the other Convection Initiation PIs, and if necessary the IHOP leaders. However, to maximize safety and minimize fatigue of NSSL teams, NSSL's mobile ground-based facilities will not operate in any data collection capacity after dusk or nightfall. All final decisions concerning the deployment of NSSL's mobile facilities during IHOP will be made by the NSSL lead principle investigator, Conrad Ziegler.

CHAPTER 4. Missions and Personnel

This section describes the NSSL-operated platforms and assigned missions of each NSSL field team (Fig. 3, Table 1). The platforms operated by the other participating institutions are also overviewed, but only the team duties and procedures for NSSL vehicles are described in detail.

Most or all NSSL teams will ordinarily be composed of at minimum a driver and a leader. The NSSL driver would ordinarily be responsible for the safe and lawful operation of the NSSL vehicle (See "Safety and Personal Considerations"). When other team members are outside the vehicle, the driver should be responsible for monitoring communications. The NSSL team leader should be responsible for all decisions concerning the NSSL team's operations, strategies, and safety. In IHOP, the Field Coordinators will provide a large amount of information for planning routes and stops, and will help coordinate overall experiment activities (See "3.2. Field Strategy"). However, mainly for safety considerations, the NSSL team leader must have the final authority and responsibility for each team. The NSSL team leader will

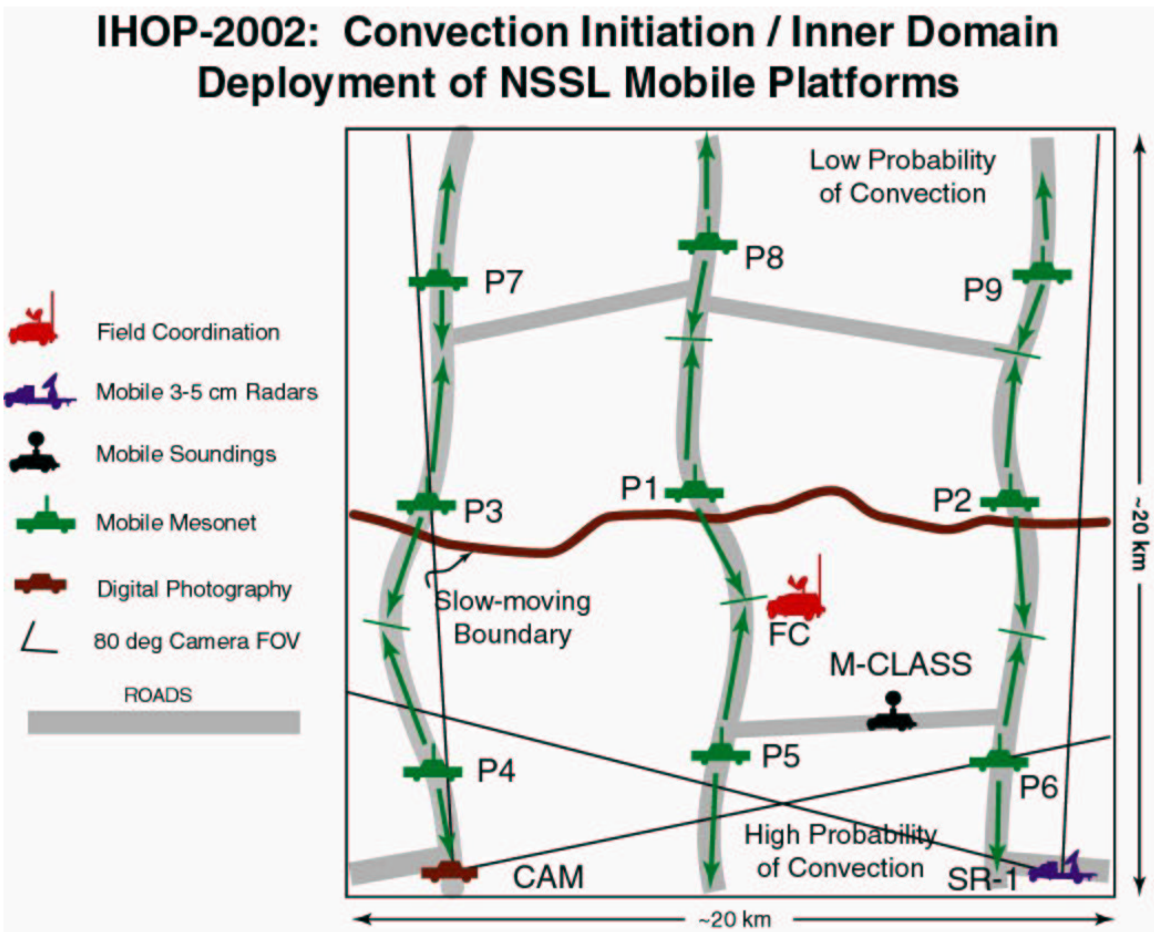


Fig. 3. The proposed deployment of NSSL's mobile, ground-based platforms in the Intensive Observing region (IOR) for the Convection Initiation (CI) study during IHOP. Boundary-crossing probes 1-3 perform "slow" legs, while probes 4-6 (in most unstable airmass) and probes 7-9 (in least unstable airmass) perform "fast" legs. Deployment locations of FC, M-CLASS, SR-1, and CAM are set relative to boundary and center location of IOR. See text for details.

Table 1. NSSL-operated mobile ground-based teams in IHOP.

Team	Full Team Name	Primary Mission
FC	NSSL Field Coordination	Facilitate mobile ground-based operations by providing local mesoscale analysis and voice/data communications hub for armada
NSSL1	NSSL mobile CLASS	1/2 - 1 hourly CLASS soundings in multi-Doppler coverage on side of boundary with highest CI probability
SR1	NSSL SMART C-band Doppler radar	Volume sector scans in IOR
PROBE1	NSSL Mobile Mesonet 1	slow boundary traverse
PROBE2	NSSL Mobile Mesonet 2	slow boundary traverse
PROBE3	NSSL Mobile Mesonet 3	slow boundary traverse
PROBE4	NSSL Mobile Mesonet 4	fast leg on side of boundary with highest CI probability
PROBE5	NSSL Mobile Mesonet 5	fast leg on side of boundary with highest CI probability
PROBE6	NSSL Mobile Mesonet 6	fast leg on side of boundary with highest CI probability
PROBE7	NSSL Mobile Mesonet 7	fast leg on side of boundary with lowest CI probability
PROBE8	NSSL Mobile Mesonet 8	fast leg on side of boundary with lowest CI probability
PROBE9	NSSL Mobile Mesonet 9	fast leg on side of boundary with lowest CI probability
CAM	NSSL camera vehicle	digital photography of IOR
SCOUT	NSSL SMART radar scout vehicle	drive ahead of SR-1 to increase safety of radar movement; digital photography of IOR
MMTECH	NSSL Mobile Mesonet technician vehicle	provide field technical support for mobile mesonets and NSSL mobile facilities

also be in charge of communications between a particular NSSL vehicle and the FC vehicle.

Unless the team leader designates a third team member to be in charge of navigation and documentation, these responsibilities would ordinarily also belong to the team leader. Detailed atlases should be provided for each vehicle. However, the FC will typically recommend routes based on the GPS positions of vehicles as overlaid on maps displayed on the two Field Coordination computers (which include all dirt roads, trails, landmarks, and terrain). The location and time of NSSL's and some other vehicles will be self-documented on the notebook system using their GPS position systems.

An important responsibility of the team leader is safety. The leader should keep a close eye on the sky, near environment, and road conditions, monitor the nowcasts of the FC closely, and communicate concerns about safety via VHF radio with the FC. Table 1 lists the mobile ground-based teams in IHOP and their broad missions.

4.1. Field Coordinator

In IHOP, mobile field operations will be facilitated from a mobile field coordination vehicle, hereafter denoted “FC” (Table 1). The FC vehicle will be operated by NSSL. The field coordinators will have a stream of real-time data spanning the mesoscale. They will receive satellite and radar imagery, as well as conventional observations and numerical guidance, via satellite. Data interpretations, forecasts, and IHOP control decisions will be disseminated via voice and Internet connections using a variety of communications devices. The FC vehicle will also receive a continuous stream of real-time mobile field data from various platforms via a mobile digital network or MDN (see section 5.4).

The FC vehicle will serve as a communications hub of the mobile field observations in IHOP. This vehicle would be equipped with a cellular phone, redundant VHF radios, a VHF repeater, an Iridium satellite phone system, and a DirecPC/Hughes self-pointing broadband Internet dish system. The FC will be equipped with a rapidly deployable 10-m pneumatic mast that will elevate the antennas for the VHF repeater and the MDN. The vehicle will be parked near the middle of the research domain, offset into the most unstable airmass (i.e. that side of the boundary with the highest CI probability) on locally high terrain. With the mast extended, VHF and MDN communications should span the IOR except for valleys and gullies. Power for the communications and computing equipment will be supplied by an internal 2 KW generator. More information on the communications protocols and procedures can be found in Chapter 5 of this manual.

The MDN data will be displayed using a custom GIS-capable software system. This is a 3-D GIS allowing the user to pan and tilt the view, as well as use fly-through techniques. This will be especially useful for understanding the 3D structure of the mesoscale phenomena being observed. For example, sounding trajectories will be plotted in 3D. Background maps will include all roads, landmarks, and high-resolution terrain data. Observations will be plotted on these maps using color-coding to depict the age of the data. Two independent displays will be utilized so that the coordinators can focus on separate aspects of coordination problems and team information needs.

The FC will have a variety of other tools available to help coordinate field activities. An example is a tool that displays dual-Doppler lobes based on proposed radar positions so that the FC can recommend deployment locations. Prior to IHOP, the coordinators will become thoroughly familiar with the operating characteristics of all the mobile systems, and will work with PI's to identify deployment strategies and particular information needs. Appropriate tools will be developed so that information requests and logistics guidance can be provided quickly when it is required. General guidance will be generated by the FC. For example, low-resolution map images showing roads, towns, pertinent observations, and hand-analyzed boundary locations can be distributed regularly via the MDN. The

Table 2. IHOP mobile ground-based platforms operated by other institutions.

Team	Full Team Name	Primary Mission
NCAR1	NCAR mobile GLASS1	1/2 - 1 hourly GLASS soundings close to and on same side of boundary as CLASS soundings
NCAR2	NCAR mobile GLASS 2	hourly GLASS soundings on opposite (least-unstable) side of boundary to CLASS
DRI	DRI mobile microwave radiometer	Sample total precipitable water and cloud in IOR
UAH	UAH Mobile Integrated Profiling System	BL profiling adjacent to boundary near highest CI probability
DOW2	X-band Doppler radar 1	Volume sector scans in IOR
DOW3	X-band Doppler radar 2	Volume sector scans in IOR
DOW4	X-band polarimetric Doppler radar 3	Volume sector scans in IOR
OU	OU 3-mm Doppler radar	Mobile RHI scans across boundary

latitude/longitude coordinates of boundaries and selected ground-based mobile platforms could also be transmitted via the MDN.

A subset of field data will be uplinked via satellite phone and broadband Internet from the FC to the NOC. Any combined data produced by the NOC and served to the Internet would often be downlinked back to the FC for near real-time guidance. The NOC nowcasters would ideally utilize real-time field observations to help provide guidance for the mobile field deployment.

The FC will provide guidance to field teams via VHF radio. Verbal summaries of boundary locations using latitude/longitude coordinates as well as landmark/azimuth/range coordinates might be "blind-broadcast" as a backup to MDN transmissions. This position information can be used by all field teams to adjust their data collection and targeting efforts with their assigned roles as described in the IHOP Operations Plan. Further, whenever appropriate, the FC will provide nowcasts of boundary motion, and diagnosed and expected changes in the structure of mesoscale circulations. Information will be broadcast regarding anticipated needs to reposition platforms.

4.2. Mobile Ballooning Laboratories

The combination of one NSSL mobile CLASS sounding system (Table 1) and two NCAR mobile GLASS sounding systems (Table 2) will be deployed inside the ground-based radar coverage in the IOR (e.g. illustrated as two systems in Fig. 3.2.1). The NSSL mobile CLASS unit will operate on the cool/moist (most unstable) side of the target boundary, and will obtain some combination of full-tropospheric soundings on a 1-h release schedule with shallower soundings on the half hour. The shallower soundings would extend through roughly one-half the depth of the troposphere and will utilize sondes with 15-min cutoff switches. The second unit would be deployed on the warm/dry side of the boundary, forming an approximately boundary-normal orientation with the first unit. Finally, the third unit would be deployed near the boundary though possibly slightly offset from the line formed by the first two units, allowing us to explore stratification near the boundary. The second and third units will also launch on a synchronized basis with the first unit, on a 30-min release schedule using 15-min cutoff devices.

The sounding sites will be based on their assigned boundary-relative positions in the IOR, as described in the IHOP Operations Plan. These sites may be moved during the course of an operations day. In some cases the sounding teams will need to receive a sounding in progress, while simultaneously preparing the next sonde and driving a short distance to the new sounding site. The FC will generally recommend a launch location along a suitable east-west highway, as well as range/heading from obvious landmarks such as town centers. Precise positioning will not be as important as attempting to adhere to the launch schedule.

The NSSL mobile CLASS sounding team should maintain an adequate supply of sondes, balloons, and helium in their vehicle. On some mornings, participants will be advised of the possibility of multi-day operations at remote locations, necessitating extra stocks of expendables in the vehicles. The FC vehicle will carry an emergency supply of extra helium.

Training in the operation of the NSSL mobile sounding system will be conducted at NSSL at the start of the IHOP field campaign.

An aircraft flying either normal to the boundary in the Doppler lobe(s) would deploy frequent dropsondes over legs much longer than one Doppler lobe diameter. To address possible frequency allocation problems, coordination of sonde frequencies with frequency bands of ARM sondes and the dropsonde band is required, as shown in Table 3. It is assumed that the dropsondes, which use a narrow-bandwidth system, will operate at a frequency between one of those listed in Table 3.

Table 3. Mobile Ballooning Frequencies

Instrument	Frequency (MHz)
NSSL1	400.00
NCAR1	405.00
NCAR2	401.00
MAPR (Homestead)	403.50
Reference Radiosonde	401.80
New Mexico (Ken Eack)	403.40
Dave Rust Nocturnal MCS	401.80
Morris OK ARM	403.50
Purcell OK ARM	401.80
Vici OK ARM	403.80
Hillsboro KS ARM	401.50
Central Facility ARM	402.50

4.3. Mobile Mesonets

Nine NSSL-operated mobile mesonets (MM) will be deployed within the IOR (Table 1). Mobile mesonet vehicles are four-door sedans with special roof racks supporting meteorological sensors. These include R. M. Young aerovane wind sensors at 3 m AGL, a relative humidity sensor, two temperature sensors (one paired with the humidity probe for derived thermodynamic variables), a pressure sensor, a flux-gate compass, and a GPS unit. The rack has a pressure port to remove turbulence-induced fluctuations from the pressure. The mobile mesonet electronics are enclosed along with the MDN radio at the base of the roof rack. The MDN antenna is mounted at the top of the instrument frame. Position and meteorological variables are computed and recorded once per second. All variables can be measured at any vehicle speed, but wind measurements are less reliable when the vehicle is accelerating. Although totally new, and improved systems will be deployed in IHOP, the earlier MM version has set a standard for high-quality, reliable data in field experiments since 1994.

Each MM vehicle will be manned by two people: a driver and a team leader. At times, a third or even a fourth person can be accomodated. It is possible to collect data with a one-person team, but owing to safety considerations it is difficult to monitor incoming data and perform effectively. Hence, we will endeavor to staff each vehicle with two people whenever possible. The team leader is responsible for data collection and satisfying the objectives of the experiment. The driver is responsible for safe operation of the vehicle.

The MM vehicles will perform continuous transects ~ normal to the target boundary. The nine vehicles will operate on 3 roughly parallel roads spaced 5-10 km apart along the boundary. To infer details, 3 boundary-crossing MMs have short legs at low speed. These three vehicles will operate at speeds of about 5-15 ms^{-1} (~10-30 mph). Team leaders should be cognizant of the likely location of target boundaries. Often, boundaries are moving so slowly that it is possible to associate the boundary location with a particular landmark (e.g. a farmhouse). Using the MM computer displays, the team leader needs to assess the magnitude of changes of state variables across the boundary, and the distance in which these changes occur. If changes are abrupt, the vehicle should be slowed to the lower end of the range of appropriate speed. If the boundary is diffuse, the higher end is to be used. The objective is to provide sufficient 1-second samples to allow researchers to assess the spatial scales and variability at the boundary.

To map larger scale "quasi-homogeneous" BL structure (eg. detect formation of new boundaries), the remaining 6 MMs will perform longer, faster legs on either side of the target boundary. Recommended sampling speeds are 20-30 ms^{-1} (40-55 mph).

The FC will advise the MM teams of the approximate endpoints of their legs, likely in terms of either latitude or longitude which is displayed continuously on the MM laptop computer. Legs should be executed repeatedly and continuously throughout the observation period. Stops should be avoided if at all possible, and the duration of any stops should be several minutes at the most. It is very important the extreme caution be used when turning around at the end of a leg; inattention to traffic could easily result in an accident. If the vehicle is being operated at a speed so slow as to impede traffic, hazard lights should be turned on, and road shoulders should be used as much as possible. Drivers must understand that road shoulders have a special set of hazards that require extra attention, such as road debris, bridge abutments, other stopped vehicles, etc. We recommend that the MM vehicles be accelerated to sampling speed as quickly as possible, thereby reducing the duration of the period in which wind data are compromised by vehicle acceleration. If dirt roads are being used for sampling, the sampling speed must be reduced for safe operation of the vehicle.

Certain phenomena should be reported to the FC using the VHF radio. The development of the first cumulus in the IOR is important information. Significant development of distant cumulus is also an important observation that will prompt the FC to analyze more distant targets for possible redeployment. However, the coordinators will not have time to debate/discuss the operational strategy, so “don’t even go there”. If precipitation reaches the ground from developing convection in the IOR, it should be reported to the FC. Finally, the coordinators will be interested in reports of well-developed dust devils (not transient vortices seemingly related to the presence of structures or trees, etc.).

The FC will receive a small subset of your digital observations (at a frequency of 1 every ~20-30 s) so that we can monitor your sampling and diagnose the evolution of mesoscale features. At certain intervals the FC will transmit an image to the MM computers showing locations of pertinent meteorological features so that team leaders can adequately determine their optimal sampling regions.

Training of MM teams will be conducted sometime around the start date of the experiment. Training will cover vehicle operation, MM operation, meteorological monitoring, communications, and safety. The training will include hands-on demonstrations and practice with MM systems.

4.4. Ground-based Mobile Radars

Volume scan clear air radial velocity and reflectivity measurements will be provided by one Shared Mobile Atmospheric Research and Teaching (SMART) Doppler radar (Table 1), three "Doppler-On-Wheels" (DOW) radars (Table 2), and a 3-mm mobile scanning Doppler radar (Table 2). Deploying 3-4 mobile ground-based Doppler radars would include the following benefits:

- decreased theoretical errors of derived vector wind field with over-determined 3-4 radar analysis;
- temporally continuous coverage of moving target boundary;
- increased areal coverage of BL environment near target boundary;
- minimum of dual-Doppler coverage given possible system failures in the field (i.e. redundant ground-based Doppler coverage).

Characteristics of the NSSL-operated SMART radar are described below, while descriptions of the other mobile radars and a presentation of multiple ground-based radar scan strategies may be found in Chapter 2 (Research radar operations) of the IHOP Operations Plan.

A multiple radar configuration provides the optimal coverage of minimum wind analysis error, assuming *over-determined* 3-4 radar dual-Doppler analysis (i.e. upward integration of continuity with two normal radar equations). Note that the over-determined 2-radar solution with 3-4 radars is superior to direct 3-radar solution near ground, the latter having vertical velocity error increasing to infinity with decreasing altitude (ie. decreasing elevation angle). The ground-based mobile sampling strategy in IHOP emphasizes the provision of near-continuous, 3-D multiple-Doppler winds in the BL within the IOR.

The SMART radar operates at C-band (~ 5 cm) and a frequency of about 5.6 GHz, and is mounted on a diesel flatbed truck. The SR-1 employs a magnetron transmitter with a solid state modulator at a peak power of 250 kW, a pulse duration in the range 300-2000 ns, a pulse-dependent PRF up to 3000 Hz, and linear horizontal polarization. The effective maximum (multiple PRF) velocity is 160 m/s. The antenna is a 2.44 m-diameter solid parabolic reflector with a half-power beam width of 1.5 deg and about 40 dB of gain. The pedestal is an extensively upgraded SCR-584 unit with an 8.5" base extension. The peak scanning rate is 36 deg/sec, although slower scanning rates will be employed in IHOP to improve radial velocity accuracy. The SMART radar utilizes the SIGMET RVP-7 digital data processor including the following features: selectable range averaging, PP or FFT processing, random phase processing, clutter filter, gate spacing, multiple PRF velocity dealiasing, and multiple quality control thresholds. Radar reflectivity, radial velocity, and spectrum width are available out to 2048 gates with minimum gate spacing of 67 m. The SMART radar has the ability to perform either sector scans and RHIs or full 360-deg sectors (including "kill-radiate" through any azimuth-elevation sector). Data archive is currently by CD-ROM using the SIGMET IRIS format.

The radars would likely be arranged in either a "box" pattern, with four radars sample the interior and neighborhood of the IOR (Fig. 3.2.1), or a "T" pattern (three radars aligned parallel to the boundary and one across the boundary). Both configurations would allow for either dual- or over-determined multi-Doppler coverage, depending on the boundary motion. Two dual-Doppler baselines would be used as a last resort, if and only if roads are insufficient for the "box" or "T" deployments. In the "box" deployment, individual radars would be spaced about 15-20 km apart. In the "T" deployment, the two radars at the head of the "T" should be close enough to ensure a minimum of dual-Doppler coverage (~ 20 km apart). If one or two of the radars are "down", the remaining radars will be operated as a 3- or 2-radar network respectively. Due to its' added service as a camera platform and as an MDN node to the FC, the SR-1 would need to be located near an IOR corner on the most unstable side of the target boundary (i.e. the side with highest CI probability).

Careful coordination between all radars will ensure simultaneous volumes and uniform spatial sampling through the boundary layer. It is important for subsequent error analysis to quantify the radial velocity standard error for radars providing clear air radial velocity measurements. Prior to the experiment, test radar scans will be performed at various sampling rates to estimate clear air radial velocity error versus in-situ data and to determine optimal sampling strategies and radar placements. Due to complex field conditions, actual radar network volume scans may gradually lose synchronization. The radars will be in constant voice communication (see Chapter 5 of this manual), and the radar coordinator frequently communicating both with the FC and the other radars, ensuring proper positioning via available roads relative to the boundary while allowing for sector adjustments to maintain synchronous scanning. The scan rates of the individual radars will be based on the lowest sampling rates that yield acceptable radial velocity estimates and achieve synchronous volume scans. As the boundary moves out of the over-determined dual-Doppler region, the trailing radar(s) will be re-deployed while the others maintain dual-Doppler coverage. A detailed discussion of the mobile ground-based radar scan strategies is presented in Chapter 2.

For increased mobile operating safety, an NSSL-operated SCOUT vehicle (Table 1) will accompany the SMART radar on *all* IHOP missions. The height of the top of the stowed SR-1 antenna is roughly 13' 6" above the road surface, requiring great care in driving the SR-1. The SCOUT vehicle will drive just ahead of SR-1 looking for hazards such a low bridges, low-hanging tree limbs and power lines, low gas station covers, or other possible road hazards. The SCOUT vehicle will also help locate radar operating sites ahead of the arrival of SR-1. The SCOUT vehicle and SR-1 will be equipped with VHF-FM transceivers and hand-held radios, allowing frequent communication of road conditions and strategy (see Chapter 5 of this manual).

4.5. Photography

Synchronized digital photographs at fixed focal length and known orientation will be obtained from two locations with overlapping views of the IOR. The digital camera platforms must be located on the side of the boundary/IOR with the most unstable airmass and the highest probability of CI. These data will be appropriate for stereo photogrammetric cloud mapping over the IOR domain. Hence, the cameras and their associated parent platforms must be deployed near the appropriate edges/corners of the IOR.

The data acquisition scheme will consist of camera systems to be manually deployed from a camera vehicle (CAM) and the SMART radar - SCOUT team (Table 1). In IHOP we are employing Sony DCR TRV900 mini-DV cameras. The TRV-900 cameras feature three CCDs and a non-interlaced scanning mode for sharp images and the capability for variable-interval time-lapse digital recording to DV tape. Images are recovered from tape to PC in post-analysis via a Firewire connection. Each camera will be fixed to a levelable tripod mount. Cameras will be powered from vehicle batteries using an invertor, with backup power provided by long-life rechargeable batteries. Hand-held compasses will be used by the camera operators to approximately aim the cameras at the appropriate azimuth angle provided by FC for each camera location in relation to the IOR center. By imaging nearby tall towers whose locations are known from the FC computer tower data base, the azimuthal orientation of the camera can be accurately computed in post-analysis from the image plane tower location and the known camera and tower locations by standard photogrammetric methods. The camera will be operated at fixed focal length, eliminating the need for photogrammetric landmark surveys. Wide-angle lenses will provide image field-of-views of about 80-90 deg. Haze and polarizing filters will be used to improve detection of distant clouds.

Analysis of the photographs will utilize digital stereo photogrammetric analysis techniques to produce maps of cumulus locations. The base and top heights of individual clouds will also be determined. In addition to the dual, tripod-mounted stereo photogrammetry cameras, IHOP will utilize an all-sky camera operated at the location of the UAH mobile profiler.

4.6. UAH Mobile Integrated Profiling System

The UAH will operate a Mobile Integrated Profiling System (MIPS) during IHOP (Table 2). The MIPS consists of the following components: (a) five-beam 915 MHz Doppler profiler, (b) 2 kHz Doppler sodar, (c) 0.905 _m lidar ceilometer, (d) a 12-channel passive microwave profiling radiometer, (e) a vertically pointing imaging camera, and (f) standard surface instrumentation including solar radiation. The 915 MHz radar measures horizontal wind, vertical velocity, and backscattered power profiles at 60-105 m vertical resolution. While average wind profiles (accuracy within ~1 m s^{-1}) are generated in real time every 30-60 min, an independent wind vector is achievable every 90 s for linear wind fields. For the clear boundary layer, the dwell time along each beam is typically ~30 s, and the vertical beam is sampled every other dwell cycle to provide information on vertical motion profiles (accuracy ~0.25 m s^{-1}) every 60 s. Doppler spectra will be archived during IHOP. Profiles of backscattered power obtained by the 915 MHz profiler provide important information on atmospheric stratification, which is particularly useful for monitoring turbulence within the ABL, water vapor gradients, stable layers, and the CBL depth.

The three-beam Doppler sodar will sample higher resolution wind profiles 25-m vertical resolution, beginning at 40-50 m AGL. With a pulse repetition period about 6 s, vertical motion is measured at about 20 s intervals, up to maximum measurement heights of typically 200-600 m. Both the 915 MHz radar and sodar will provide important information on ABL turbulence using the mean velocity and spectrum width fields. The sodar also provides the acoustic source for profile measurements of virtual temperature (T_v) via the Radio Acoustic Sounding System (RASS) technique. Profiles of T_v will be acquired at time intervals of 30 min or less. Cloud base, cloud thickness and visibility profiles (e.g., relative aerosol loading) will be obtained by the lidar ceilometer, which acquires measurements of backscattered power at 15-m intervals, beginning at 15 m AGL. Time resolution will be set at 15 s. Cloud visual properties and coverage fraction will be documented by a vertically pointing camera (40-deg field of view) at 2-s time resolution. The 12-channel radiometer will measure temperature, water vapor density and cloud water (at cruder resolution) profiles up to 10 km AGL (greatest vertical resolution at low levels) at 10 min intervals. The surface measurements (T, RH, p, wind direction/speed at 10 m, and solar radiation) will be recorded at 1 Hz. We will also include a Gill 3-component anemometer and fast-response temperature and humidity probes to estimate vertical fluxes of heat and water vapor.

Data from the MIPS are archived on computer hard disk, and can be backed up on tape or CD media. Displays of the data (time vs. height sections of mean wind, and moments from individual beams) are produced in near real time and more extensive analyses will be accomplished within one day of data collection.

The MIPS will typically be located within good dual- or multiple-Doppler coverage, close to boundaries. For slow-moving boundaries, we plan to move the MIPS to new locations when the boundary moves beyond the MIPS site. Combined dismantling setup time is estimated to be 5 min. For fast moving boundaries (>10 m s^{-1}) only one sample is probably achievable. Hence, mobile sampling in IHOP will concentrate on slow moving boundaries.

The general research goal is to characterize each boundary (or BL vertical motion event) and its attendant cloud fields that pass over the MIPS site within the mobile network. Parameters measured by the MIPS, such as maximum vertical motion within the boundary zone, boundary width, cloud base height and cloud coverage (if clouds exist), horizontal gradients in T_v, and boundary layer properties (e.g., stability, mean wind profiles, turbulence characteristics, BL depth, gravity waves) will be determined across the boundary. In addition, the MIPS data will define relations between boundaries, *w* and water vapor enhancement (increases in magnitude and depth) within and above convergent boundaries.

A second goal is to conduct a detailed case study of convective initiation to determine the mechanism(s) responsible for CI, and the properties of the BL and convergence line/region accompanying the CI process. We are most interested in examining the structure and evolution of boundaries during the afternoon to evening boundary layer transition period.

4.7. DRI Mobile Microwave Radiometer

The Desert Research Institute (DRI) will operate a Mobile Microwave Radiometer (MMR) during IHOP (Table 2). The MMR is a dual-channel instrument that operates at frequencies of 20.6 and 31.65 GHz. The 20.6 GHz channel is sensitive mainly to emissions from water vapor, and the 31.65 GHz channel, in an atmospheric transmission window, is more sensitive to liquid water. The instrument measures brightness temperature at each frequency, from which absorption is computed. Statistical retrieval techniques are then used to compute path-integrated depths of water vapor and liquid water. The atmospheric retrieval coefficients are computed using a radiative transfer model on a set of soundings relevant to the location of interest.

The radiometer receiver, computer, and antenna control mechanism are housed in the cargo area of the vehicle. A 6.5 kW power generator installed into a sound- and heat-insulated compartment serves as the power source for the instrument in mobile mode. The generator can power the radiometer for up to 24 h of mobile or remote operation. Typically, two people are involved in operations: a driver and an instrument operator. Vehicle position is recorded from a GPS receiver. Surface temperature and humidity are also recorded. The antenna for the system yields a 2.5º beam sampling width. A spinning reflector is used externally to direct microwave emission to this antenna and to repel precipitation particles from the reflector surface. In stationary operation, the antenna housing can be pointed vertically or be rotated to collect data in scans at fixed elevation angles. For mobile operation, the antenna is locked to a zenith-pointing position. Data are typically averaged over a period of about 1-5 seconds. At a cruising speed of about 50 km/hr, this translates to a spatial resolution of 14-70 m.

During IHOP, the DRI mobile microwave radiometer will collect ~20 m resolution observations of vertically integrated water vapor and liquid water (1 s samples at a speed of 20 m s-1) while operating in mobile, zenith-pointing mode. A mobile system will provide the added ability to sample in the horizontal, with the flexibility to sample at desired locations in coordination with other complementary observations. The primary objective of this data collection effort will be to test the hypothesis that initiation of deep convection is preferred at locations of maxima in magnitude and depth of water vapor along various types of boundaries such as drylines, gust fronts and horizontal convective rolls. A related objective will be to determine if these local maxima have a systematic relationship with the associated kinematic field measured by other observing systems.

During slowly evolving periods, the DRI mobile microwave radiometer will execute a "horizontal picket-fence" pattern with three, 10-20 km (8-16 minute) cross-boundary legs. At least one of these legs will be bounded on each side by soundings released 1-2 per hour by the mobile sounding systems (MGLASS and/or MCLASS). One of the DRI MMR traverse legs will be chosen to pass the fixed UAH MIPS, providing independent radiometer measurements of the same BL column from the two platforms. When evolution is more rapid, the mobile radiometer will focus on a single cross boundary leg that is located to complement other mobile observations. Another important attribute of the mobile radiometer is its ability to collect meaningful water vapor data in the presence of clouds. Water vapor information from DIAL systems may be limited in these conditions, especially in the case of the downward-pointing airborne DIAL. Since the initiation of deep convection generally occurs in the presence of an evolving cumulus field, mobile radiometer observations may be critical in filling gaps in the DIAL observations caused by clouds.

4.8. Coordination with Aircraft for CI, ABL-CI, and sunrise BL missions

The NRL P-3, the University of Wyoming King Air (UWKA), the DLR Falcon, and the Flight International Learjet dropsonde aircraft will be deployed in close coordination with mobile ground-based platforms on CI missions (Fig. 4). These aircraft will also support joint ABL-CI and sunrise BL missions. The NASA DC-8 and the NASA Proteus aircraft (not shown in Fig. 4) will also be deployed during IHOP. Aircraft legs would be flown through and in the near vicinity of the IOR. Details of the aircraft operations are described in Chapter 6 ("Aircraft operations") of the IHOP Ops. Plan. In summary, the P-3 would fly a narrow (80 km x 15 km) "racetrack" pattern along the target boundary or feature at ~ 300 m, with the DIAL lidar pointing in toward the boundary. The UWKA would fly some combination of an along-boundary traverse (~ 300 m) or "P", boundary-normal stacked traverses (~ 30-100 m, $0.6Z_i$, and $1.5Z_i$) or "NS", and a box ($1.5Z_i$) pattern or "B" inside an area ~ 50 km x 30 km centered on the IOR. The DLR Falcon and dropsonde aircraft would fly ~ 50 km- to 100 km-long boundary-normal mid-tropospheric legs directly over the IOR. In the event of UAV participation, two configurations have been considered: (1) a vertical stack about 20 km (11 nm) long and between 30 m and 700 m AGL (100 – 2300 ft); (2) spaced horizontally at some level within the latter altitude interval.

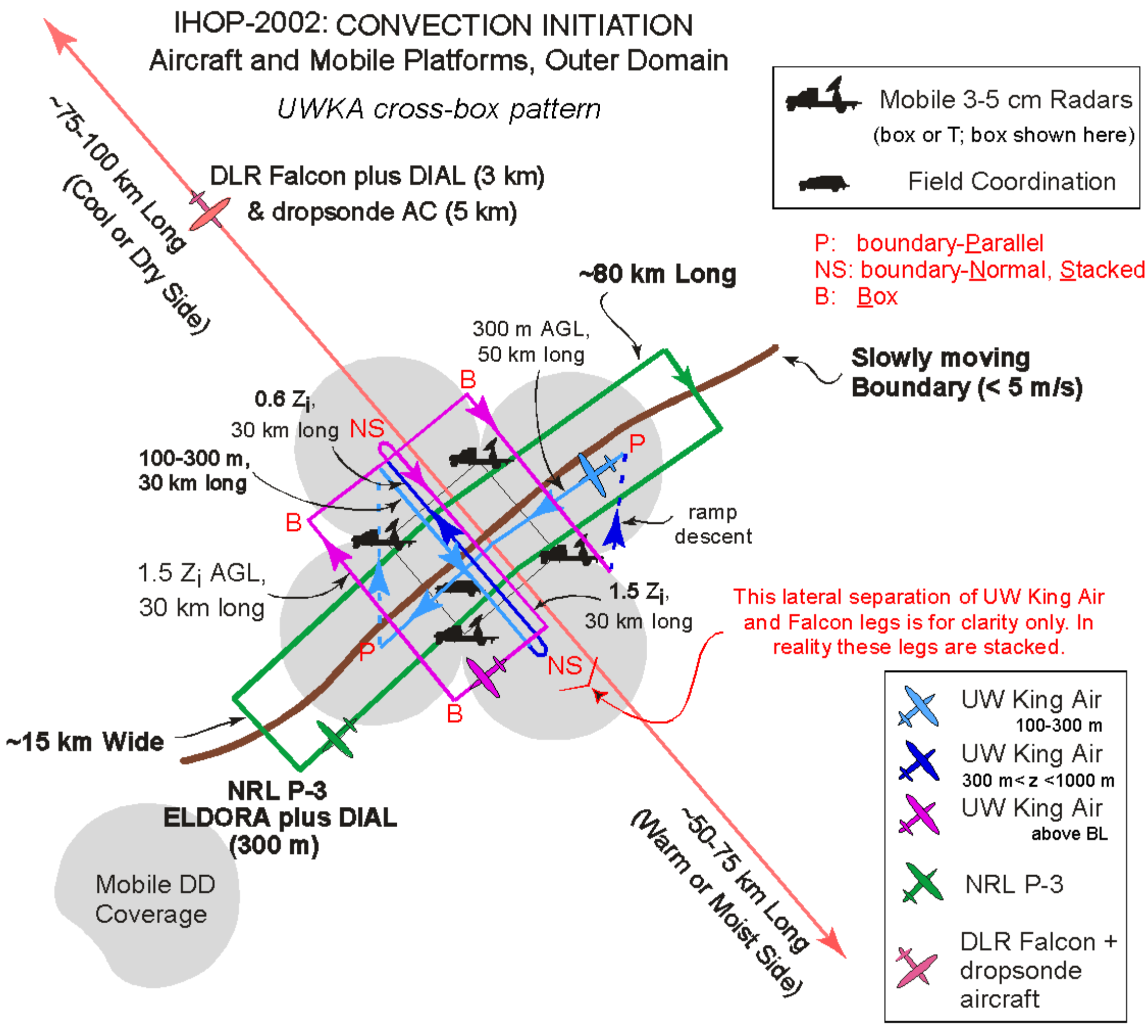


Fig. 4. The proposed deployment of aircraft relative to radars and other mobile, ground-based platforms in the Intensive Observing region (IOR) for the Convection Initiation (CI) study during IHOP.

Communications between the ground teams and the aircraft will be important for coordinating airborne and ground-based data collection (see Chapter 5 of this manual). As in past experiments, we will rely on VHF radio communications between the FC and the Chief Scientists or their designated Communicators on the four aircraft. Alternatively, the FC and P-3 Chief Scientist could communicate strategies, and the P-3 or UWKA Chief Scientist could then coordinate with the flight crew and the Chief Scientists on the other aircraft. As always, VHF air-ground communications are facilitated when aircraft are flying straight, level, and at altitude. Though aircraft cabins are typically a noisy environment at altitude, satellite phone communications are an alternative for air-air and air-ground coordination between the FC and P-3. Digital data communications will be possible via the MDN links between the FC, P-3, and UWKA (see Chapter 5).

Having established the mission and preliminary target of the Day 1, either the P-3 or a ground team will arrive first in the target area and probe the location and approximate orientation of the boundary. This information will then be shared between the FC and P-3, with subsequent dissemination to the other aircraft and ground teams (see "3.4. Communications"). Airborne and ground-based legs will then be coordinated based on the preset mission profiles (see "3.2. Field Strategy ") and the input target boundary location and orientation.

Dropsondes would be deployed from the dropsonde aircraft at the maximum possible rate (~ 15 km along-track spacing). Coordination of dropsonde and upsonde frequency allocations is required prior to the beginning of the IHOP field phase (see "Table 3.3.2. Mobile Ballooning Frequencies").

4.9. Base locations of ground-based mobile facilities

The NSSL-operated mobile facilities, including the SMART radar and scout vehicle, the mobile mesonets, the NSSL mobile CLASS laboratory, the camera vehicle, the FC vehicle, and the mobile mesonet technician's vehicle, will be based out of Norman, OK (Fig. 1). The DOWs, the UAH MIPS, the NCAR mobile GLASS sounding systems, the DRI mobile radiometer, and possibly other mobile platforms to be based out of Liberal, KS (Fig. 1). Basing the NSSL platforms in Norman greatly reduces the operating costs of the NSSL armada by using NSSL maintenance facilities and locally available staffing.

Given the need to get on station by ~ 2 pm LDT, and up to ~ 4-5 hour to ferry from base to target on some missions, the NSSL ground-based contingent might need to leave base by not later than ~ 9-10 am LDT. To achieve early departures, the forecasting and targeting decisions should be streamlined. The initially broad target area could be refined using later guidance and observations during the time period the Norman and Liberal mobile ground-based contingents are ferrying. The Norman- and Liberal-based ground teams should converge as quickly as possible to the designated target area, while communicating between themselves, with each other, and with the NOC (see Chapter 5).

CHAPTER 5. Communications

5.1. VHF-FM Communications

Most or all mobile IHOP platforms will be equipped with VHF-FM transceivers. All IHOP participants are welcome to utilize the NSSL VHF communication frequencies provided they have the appropriate equipment. To optimize communications, it is recommended that all teams follow the communication protocols outlined below. The FC vehicle has been designed to accomodate radio communications with aircraft and ground-based platforms (Fig. 5).

VHF transceivers, with transmitted power adjustable from 5 W up to 55 W, normally provide voice communications over several miles in range in the case of a ground-level transmitter-receiver pair. If the terrain between vehicles is flat and unobstructed (e.g. flat prairie, air-ground communications), the range can be greater. Using a web utility program for ham radio operators, we have calculated an RF horizon distance from a 10 m (FC) antenna to mobile ground-based platforms as ~ 22 km. Hence when data-gathering operations commence and the FC vehicle is parked on higher terrain with the repeater operating and the mast extended, VHF communications should be achieved over essentially the entire IOR domain. Of course, if a vehicle is in a valley or gully, its radio communications could be temporarily interrupted.

Three VHF frequencies are permanently assigned to NSSL, and are available for use in IHOP. These are 163.100 MHz (primary transmit frequency, simplex receive frequency), 165.435 MHz (repeater transmit, or duplex, frequency), and 163.275 MHz (special use ONLY). The VHF transceivers on all NSSL vehicles have been programmed to handle frequency selection simply by selecting the correct channel. In IHOP, Channel 1 will be designated as the primary simplex channel (163.100 MHz). In simplex mode, radios transmit and receive on the same frequency. Channel 1 will be utilized whenever the repeater (described below) is unavailable, owing to distance, terrain, or experiment mode. Channel 2 will be utilized for duplex communications (i.e. involving a repeater). In this mode, the repeater in the FC vehicle receives at the simplex frequency (163.100 MHz) and transmits at the duplex frequency (165.435 MHz). The aircraft will be able to both transmit and receive all ground communications at the simplex frequency, 163.100 MHz, regardless of whether or not the repeater is operating.

The FC will advise teams concerning which channel is most appropriate. When in doubt, it is sufficient to simply switch to Channel 2 and attempt to contact the FC, or else to key the microphone. If Channel 2 is being used (repeater operational), a few seconds of reduced radio noise would be heard as the repeater continues transmitting followed by a beep. If the beep is not heard, use Channel 1 instead. Channel 3 (163.275 MHz) will be available for off-line communications between selected ground-based mobile platforms. Channel 4 (151.940 MHz) should be reserved for off-line conversations between the DOW and SMART ground-based mobile radars.

5.2. Voice (VHF-FM) communication protocol

Adhering to a strict communications protocol would greatly facilitate smooth and productive IHOP operations. The success of the experiment hinges on the concept of efficient, timely field coordination, and this in turn requires that radio traffic be kept at the minimum necessary level. Therefore, the FC will utilize broadcasts, at regularly scheduled intervals, of relevant weather information (nowcasts). Each nowcast will be announced in advance (.e.g. "all teams, stand by for a nowcast in 30 seconds") so that team members will be prepared to take any necessary notes relevant to their missions.

In normal circumstances, communications with NSSL vehicles will be initiated by the FC. NSSL teams should initiate radio calls only in the event that they need information vital to performing their data-gathering missions, or to report meteorological phenomena as specified in the IHOP Operations Plan.

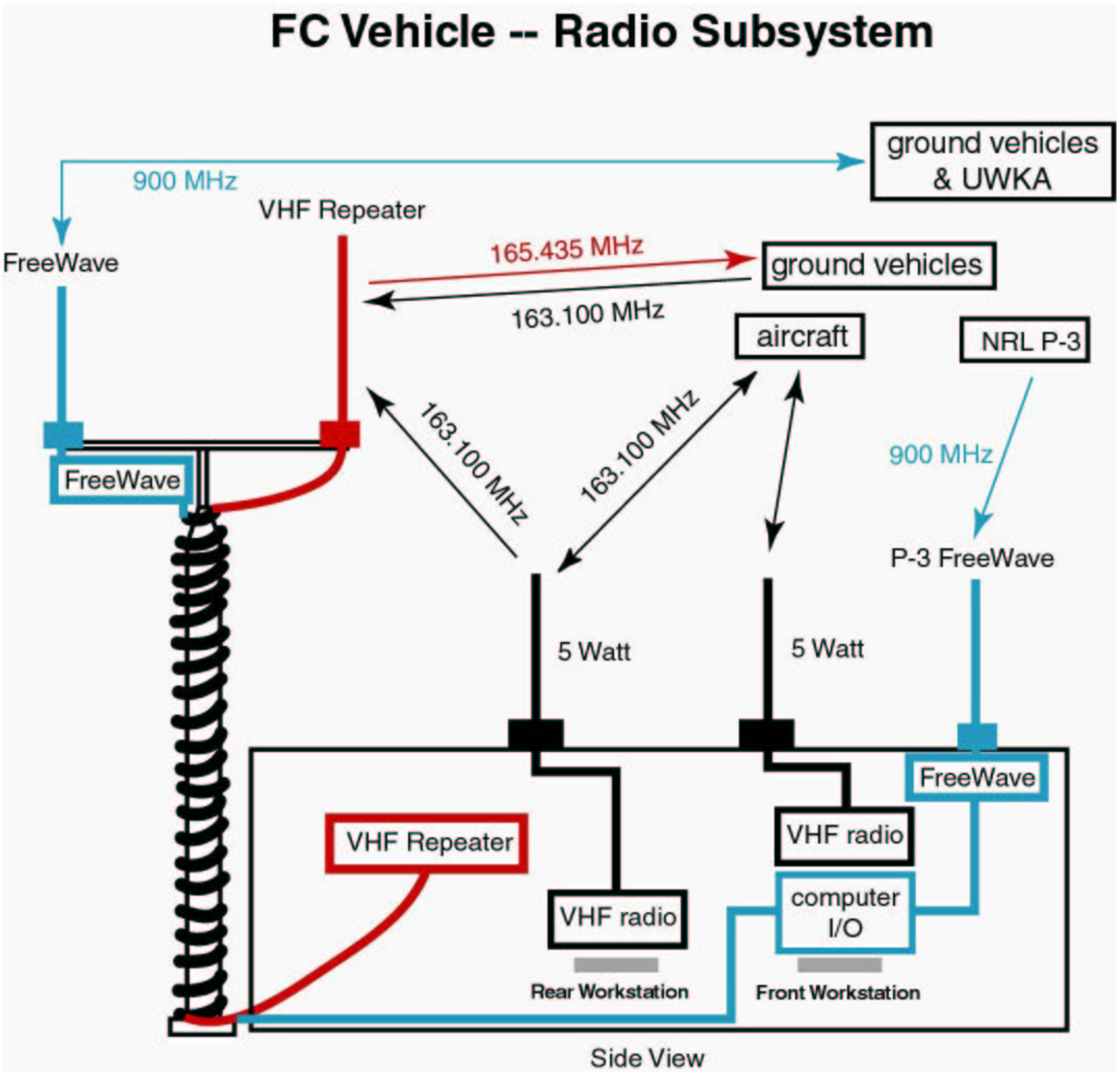


Fig. 5. Schematic diagram of VHF-FM and 900 MHz mobile digital network (MDN) communications between the field coordination (FC) vehicle and airborne and ground-based platforms during IHOP. Arrows indicate direction(s) of voice and data transfer. See text for details.

IHOP participants must understand that the "NSSL frequencies" are government frequencies that are often scanned and monitored by people external to the project. Professionalism is important. When data-gathering is not in progress, more general conversation and “radio chat” will be allowed. However, under no circumstances should profanity or vulgarity be used, and participants should be sensitive to the fact that citizens might judge how well their tax dollars are being utilized as they listen to our radio frequencies.

The following radio protocols are designed to help ensure the best use of the NSSL frequencies during IHOP:

- Inter-team communications on the Channel 1 and 2 IHOP frequencies are discouraged. Certain teams may use IHOP Channels 3 or 4 for mission-critical communications. If other inter-team communications are required, use other means wherever possible (e.g. cell phone).

- Teams may initiate contact with the FC to notify them of a change of their status (i.e., stopping for data collection, rolling, stopping for gas/supplies, etc.). Teams are encouraged to report a meteorological phenomenon that has not already been reported (e.g. dust devil, new developing cumuli), or to request route or data collection guidance.

- When initiating contact, follow the following protocol example: " FC, PROBE1." (Think: FC, this is PROBE1). To give PROBE1 permission to speak, FC will respond with " PROBE1, FC, go ahead" or simply "FC". If the communication cannot be accommodated, FC will say (e.g.) " PROBE1 stand by".

- If contacted by the FC, the first message from the FC will be as in this example: " PROBE1, FC". A simple response identifies the responding vehicle; e.g. " PROBE1" . The FC will follow your identifier response with additional communications (e.g. " PROBE1 you should consider turning northeast on state highway 9 in about two miles, just past a sharp left jog in the road.").

- Keep all communications as brief as possible, preferably 10 seconds or less. Short transmissions make it possible for other users with more urgent communications to break in and utilize the channel. Think about what to say *before* initiating the radio transmission!

5.3. Cellular Phone

Certain teams will carry digital cellular phones, including the NSSL-operated FC vehicle, the SMART radar, the mobile CLASS sounding vehicle, and the MM technician's vehicle. These could be very useful, should there be a failure in or restriction of the VHF communications. All four NSSL vehicles with cell phones will have rooftop-mounted, magnetic puck antennas to boost signal strength. The mobile ground-based radars will also need to communicate with each other frequently to establish and maintain scan synchronization, providing another important application of cell phones. By agreement of individual PIs, phone number lists could be selectively distributed at the start of the experiment to facilitate field communications.

5.4. 900 MHz mobile digital network

A technology known as the mobile digital network (MDN) will be implemented for the first time during IHOP. This system will be based on FreeWave 900 MHz radio frequency modems. These radios utilize rapidly modulated frequency-hopping to find the best available channel within a narrow band around 900 MHz. They are capable of rudimentary network operations, such as Master/Slave configuration, repeating, and store/forward caching. In typical operations, multiple, spatially distributed "Slave" radios transmit data to a single "Master" radio. At 1 W output power, the approximate air-ground range of the 900 MHz radios is roughly 40 km or more. For 900 MHz transmission between ground vehicles, the radio horizon depends on the exposure and height above ground of the respective antennas. For communications between probes and the FC, with its 900 MHz antenna mounted on its 10 m deployable pneumatic mast, the expected radio horizon is comparable to that for VHF communications as previously described (i.e. roughly 20 km). In the point-to-point mode, the nominal data rate is 115,000 bps.

Plans call for the FC, the MM vehicles, the NSSL mobile sounding vehicle, the SMART radar, the P-3, and the UWKA to be nodes of the MDN (Fig. 6). Additionally, it is planned for the NCAR S-Pol radar and the DOW mobile radars to have 900 MHz radios for the purpose of receiving transmissions

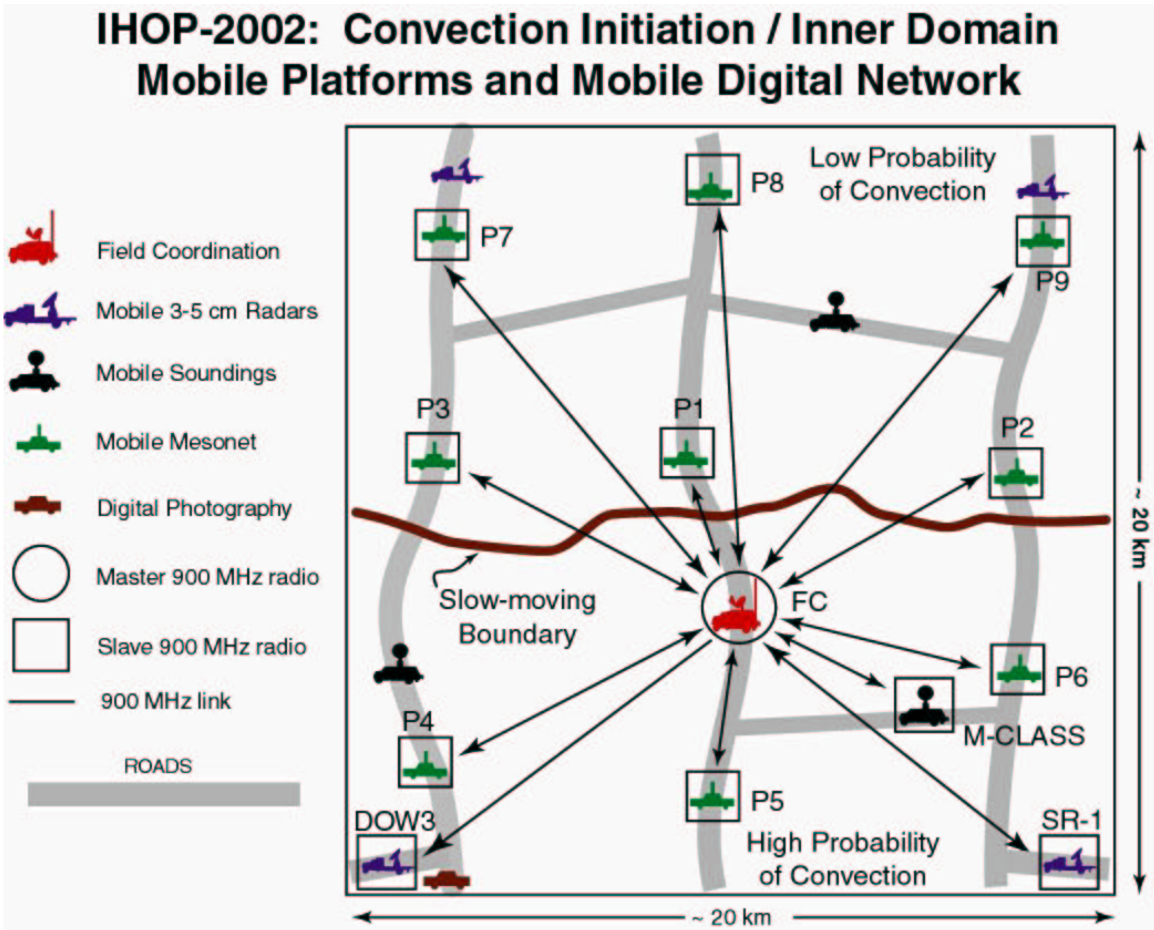


Fig. 6. Schematic diagram of the configuration and function of the mobile digital network (MDN) relative to mobile, ground-based platforms in the Intensive Observing region (IOR) for the Convection Initiation (CI) study during IHOP. For illustration, radars are arranged in the "box" mode described in the text. Arrows indicate direction(s) of data transfer via the 900 MHz frequency-hopping radio modems. See text for details.

from the P-3 and FC radios. Other researchers are welcome to link their platforms to the MDN. The requirements are a FreeWave modem that has been interfaced to the computer system of their platform, as well as provision of a (preferably) compact data format to NSSL that would be used to transmit their data across the MDN.

The planned mobile digital network configuration calls for each platform to transmit their cached data to FC at regular intervals. The FC computer will ingest the MDN data transmissions, and information will be sorted, processed, and presented on a "tactical display" of the current deployment and observations of the armada. Given the number of transmitting Slave radios and the fact that the master radio can only listen to one Slave transmission at a time, the key to a smoothly operating MDN is for the individual Slave transmissions to be relatively compact (i.e. brief) and sparse (i.e. spread out in time).

It is anticipated that mobile field observations would be updated roughly on a 1-5 min cycle. The cycle period will depend on the number of nodes, the length of individual data packets, the average number of attempts required for successful packet transmission, and the amount of data to be transmitted to the MDN from FC. MM data could be updated as quickly as every minute. Mobile soundings would be transmitted at roughly the time the sonde reaches the top of the ABL and then again when the sonde reaches the top of its flight. Mobile Doppler data (probably base scan reflectivity image only) could be transmitted once per volume scan (~ 3 min) or every other volume scan. Additional in-situ data will be transmitted from the P-3 and UWKA.

These MDN data will be combined by the FC computer into a 2-D or 3-D GIS visualizations for real-time field coordination, archived for quick-look operational reviews, and transmitted in near real-time for Internet distribution. The FC may periodically transmit low resolution graphical images of the tactical display (i.e. "screen dumps") to all Slave radios, providing the armada with a physical location and context of the individual platforms with respect to the mesoscale boundary or other feature being sampled. The FC may optionally broadcast other textual nowcast and summary information to the entire MDN. These packets could be captured and displayed on the computers of the various field teams for guidance.

5.5. Internet communications

The FC is equipped with an Iridium satellite phone and a DirecPC/Hughes 2-way, broadband satellite Internet dish system. The satellite dish system, which can be operated when the FC vehicle is parked in the field during operations (i.e. its normal operating mode), can routinely achieve ~ 80 kbps upload and 1.5 Mbps download speeds. The Iridium phone, which can be operated either while parked or moving and also handles both voice and data, can achieve 2400 bps for short e-mail messages.

The satellite dish and Iridium phone will be used for connection to the Internet via UCAR/JOSS in Boulder, Colorado. UCAR/JOSS will serve FC data products via the Internet to servers at the NWS/NCEP/SPC, NSSL, and the NOC in Norman, OK. These data will be converted to standard formats and served to the WWW, facilitating their perusal and interpretation. Typically available WWW data will be used for mission planning and coordination, and to enable FC to be “reading off the same page” as the IHOP Operations Center. CLASS soundings and other local armada observations will be available to IHOP nowcasters to help them place our fine-scale measurements into the context of larger-mesoscale operational surface, radar, satellite, and upper air observations. This near real-time data from FC should prove useful for overall experimental oversight and a unique capability for “virtual participation” in IHOP.

CHAPTER 6. Safety and Personal Considerations

Safety and highway courtesy will be a fundamental consideration during NSSL's mobile ground-based field operations in IHOP. Any NSSL vehicle operator engaging deliberately in unsafe or unlawful behavior will not be allowed to participate further in field operations. Perhaps the first safety concept to understand is that no field crew will exceed the posted speed limits at any time. With the direction of the Field Coordinator, no NSSL crew will be asked to exceed the speed limit in the execution of their duties. If it appears that the NSSL crew cannot meet their assignments without exceeding the speed limit, they are to notify the Field Coordinator immediately.

In IHOP, some of the NSSL mobile platforms will be driven to a location and parked for a period of tens of minutes to hours. It is very important that these vehicles be parked as far away from highway driving lanes as feasible. If the vehicle is close to a driving lane, it should be parked so that oncoming vehicles can see the parked vehicle from a good distance, and orange hazard markers should be placed along the roadway to alert oncoming traffic. The strobe hazard lights should be turned on to warn approaching vehicles.

Mobile mesonet operations for clear-air sampling entail certain unique hazards. The vehicles typically will be operated at speeds somewhat less than normal highway speeds. Consideration must be given to the hazard this presents to cars overtaking the vehicles from the rear. If operating the vehicle slowly enough to surprise approaching drivers, the stobe hazard lights should be turned on. If operating the vehicle so slowly that overtaking vehicles are at risk of collision, consider driving on the shoulder with the strobe hazard lights on. However, there are typically more hazards on road shoulders than in driving lanes, such as road debris, bridge abutments, parked vehicles, etc. Drive with great awareness concerning overtaking vehicles and roadside hazards. Be especially cautious when re-entering the driving lane from the road shoulder.

Mobile mesonet sampling will require an expedited turn-around at the end of the transect legs. There are three safe ways to do this maneuver. On lightly-used roads, pull to the right shoulder, check carefully for oncoming *and* overtaking traffic, and perform a U-turn into the opposite lane when clear. Alternatively, make a left-turn onto an adjoining road or field entry, back up onto the right shoulder, and then pull into the driving lane when safe. If traffic is especially heavy, it is safest to make a right turn onto a connecting lightly-used road, do a U-turn there, and then make the left-turn onto the highway to resume transects when clear. These turnarounds will prove to be the most dangerous part of MM sampling, and great caution is required.

As IHOP/CI is not a storm intercept experiment, the crews should not have to deal with rain, hail, and wet roads. However, often the teams will encounter poor weather during the evening return trips to the overnight location. Hydroplaning is a major item of concern, and if there is any doubt about the situation, the first response should be to slow down and exercise good judgment. Water on the roads deep enough to cause hydroplaning may not be obviously visible, so caution must be exercised on any wet roads. In fact, loss of control of the vehicle on wet roads is possible even when hydroplaning is not involved, if the vehicle is moving too fast for the conditions. During rain, driving conditions can and do change suddenly, and drivers need to be alert to the possibility of changing road conditions at all times.

Generally, unpaved roads are not recommended if there has been rain in the previous 24 h. The FC should be able to provide guidance on the quality of unpaved roads; consult with the FC before using them. Many roads in Oklahoma (and elsewhere) do not have good shoulders to forgive any problems that might arise; often a deep, muddy bar ditch awaits any careless maneuver.

The following are some suggestions for the field crews to make participation as comfortable as possible. First of all, everyone should be prepared for the conditions they may well encounter. Participants will be spending long and occasionally tedious hours in cramped vehicles. Do what it takes to be comfortable while maintaining safety. It makes sense to have some sort of rain gear, preferably a rain suit rather than a poncho, which the wind can blow about and render ineffective against the rain. A change of shoes and socks might be useful (muddy, water-filled ditches!). In fact, it would be prudent to have a full overnight kit on each mission as some missions may well turn into overnight events. Be sure to bring along any personal medications you need, including allergy medicine, pain relievers, antacid tablets, and so forth for minor discomforts. Be sure to let the rest of the team know in advance about any medical conditions (e.g., asthma) or allergies (e.g., to bee stings or to penicillin).

While it is possible to make brief stops to buy snacks and drinks on the road, it is best to bring along any needed snacks and drinks, as the team will not be able to stop for purchasing these items during data-gathering operations. Consider the area being deployed to, and plan accordingly. Bring a sack lunch on each mission, in case teams cannot stop for a lunch break. Drinking a lot of fluids on the drive has certain inevitable consequences; if you drink only enough to avoid dehydration, then you won’t have to stop at an inconvenient time. Remember that bathroom breaks will not be possible during data-gathering operations, so plan accordingly.

Sunglasses are quite useful, particularly if they are UV blockers and even polarized to reduce glare. Headaches can result from glare associated with excessive sunlight. A hat with a brim is useful to screen eyes, face, and neck from the direct sun. If fair skinned, be sure to bring along and/or use a sunscreen, and long sleeves may be a viable option. Grassy roadsides are often full of chiggers and ticks. Insect repellent applied to pants and/or legs (if wearing shorts) can reduce this annoyance considerably. It is useful to have a jacket or windbreaker along, since it can get quite cool late in the day near a thunderstorm (outflow can be downright chilly!).

All participants should be well-rested at the start of an intercept. On the trip home, change drivers as necessary to avoid fatigue. Each vehicle should have a simple first aid kit and a flashlight.

Summary: Safety Rules for NSSL's field teams

A. Traffic hazards

- Wear your seat belt! If you don't, the government does not insure you in the event of an accident. Watch out for other drivers.
- Do not speed.
- Drive only as fast as conditions allow.
- Drivers watch the road; not dust devils, clouds, storms, other passengers, etc.
- Front-seat passenger should assist driver. Do not assume driver is going to stop. Do not let driver nod off.
- Watch for unmarked RR crossings.
- Do not swerve suddenly to avoid small animals.
- Avoid section roads to the greatest possible extent. They may dead end and may become extremely slick or impassable when wet.
- Watch out for debris in road or drooping power lines.
- Do not stray away from your vehicle.
- Do not run low on gas.
- Do not drive into restricted areas such as military bases. You may be trapped by closed gates.
- The driver is responsible for all tickets.
- When driving through or near a town that has been hit by a tornado, remember the power may be out causing traffic disruptions and preventing you from refueling. Be alert for emergency vehicles.

- Do not drive into smoke or blowing dust that obscures your view. If heavy rain obscures your view, it would be wise to pull over if there is a paved shoulder to avoid being hit from behind.
- When backing up, have passengers assist you by watching for obstructions.
- MM teams observe the special safety precautions outlined above.

B. Vehicle roll-over hazard (adapted from NHTSA guidelines)

- All vehicles, but especially 15-passenger vans such as FC, may be subject to roll-over hazard.
- Three leading causes of rollovers when driving at highway speeds: (1) vehicle runs off rural road; (2) the driver is fatigued or driving too fast for conditions; (3) the driver overcorrects the steering, either as a panic reaction to an emergency or to a wheel dropping off the pavement.
- BUCKLE YOUR SEATBELT to offer the best chance of protection in the event of a roll-over accident.
- Minimize risk of a roll-over: (1) avoid conditions that lead to a loss of control; (2) drive cautiously, especially on rural roads; (3) if wheels drop off roadway or pavement, gradually reduce speed and steer back onto the roadway when it is safe to do so; (4) keep tires properly inflated.

C. Miscellaneous hazards

- Snakes, particularly on shoulders of road.
- Chiggers, mosquitoes, bees.
- Dress for all weather contingencies.

APPENDIX A. ABBREVIATIONS

CAPE	Convective Available Potential Energy
CAPS	Center for Analysis and Prediction of Storms
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CIN	Convective Inhibition
DRI	Desert Research Institute of the University of Nevada, Reno
FC	Field Coordinator
GSA	Government Services Administration (U.S. Government)
HPCC	High Performance Computing and Commmunications program
IHOP	International H_2O Project
MM	Mobile Mesonet
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NOC	Norman Operations Center
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory
NCAR	National Center for Atmospheric Research
OU	University of Oklahoma
TAMU	Texas A & M University
TTU	Texas Tech Universtiy
UAH	University of Alabama - Huntsville
USWRP	United States Weather Research Program
UCAR	University Corporation for Atmospheric Research
OFPS	Office of Field Program Support

APPENDIX B. PHONE NUMBERS

The following phone numbers are available for use by both NSSL mobile ground-based teams and IHOP participants collaborating with NSSL teams. Unauthorized calls or calls from other than IHOP personnel will not be accepted by NSSL field teams.

NOC voice	(405) ___-____
Recorded NOC IHOP voice status message	(405) ___-____
Recorded NSSL voice status message prior to departure	(405) 366-0486
FC cell phone (C. Ziegler)	(405) 517-0607
FC Iridium phone (land-to-handset calls will be returned)	(special use only)
SR-1 cell phone	(405) 517-0608
NSSL1 cell phone	(405) 517-0609
Mobile Mesonet technician cell phone (S. Fredrickson)	(405) 517-0610
FC Office	(405) 366-0489